

**INSIGHTS INTO
EEDI AND MPP
VERIFICATION
PRACTICES**

Large Tankers
and Bulk Carriers



INSIGHTS INTO EEDI AND MPP VERIFICATION PRACTICES FOR LARGE TANKERS AND BULKERS

OVERVIEW

In 2011, the International Maritime Organization (IMO) established the Energy Efficiency Design Index (EEDI), as a goal-based technical standard to reduce the greenhouse gas (GHG) emissions generated by the shipping industry. Starting on January 1, 2013, an initial two-year 'Phase 0' required new ship designs to meet the reference level for their specific ship type. From that point on, new designs are required to become progressively more efficient in three more 'Phases' reaching a 30% reduction in CO₂ emissions between 2025 to 2030 for applicable ship types. The regulations on EEDI are designed in such a way to stimulate continued innovation and technology development of key components influencing the fuel efficiency of a ship from its design phase.

In addition to EEDI, there are IMO requirements addressing the Minimum Propulsion Power (MPP) for safe maneuvering of ships in adverse conditions. A key component of MPP is added wave resistance (RAW).

As the EEDI requirements become more stringent through the implementation phases, it becomes a design challenge for large tankers and bulk carriers to meet the EEDI and MPP requirements simultaneously.

This whitepaper provides updates on the regulations and supporting guidelines for minimum propulsion power and added wave resistance. The document also introduces the industry practices and recent efforts to address the challenges.

OVERVIEW OF INTERIM GUIDELINES FOR MINIMUM PROPULSION POWER

Since the International Maritime Organization (IMO) developed the Energy Efficiency Design Index (EEDI) concept in 2013, more stringent requirements have been introduced through implementation phases. While designed to improve energy efficiency, the EEDI requirements also include provisions for Minimum Propulsion Power (MPP) which enable a vessel to maintain maneuverability in adverse weather conditions.

Specifically, Regulation 21.5, Chapter 4 of MARPOL Annex VI requires that “For each ship to which this regulation applies, the installed propulsion power shall not be less than the propulsion power needed to maintain the maneuverability of the ship under adverse conditions as defined in the guidelines to be developed by the Organization”.

The IMO interim guidelines for Minimum Propulsive Power assessment were initially published in 2013 by Resolution MEPC.231(65) and currently apply to:

- Tankers
- Bulk carriers
- Combination carriers

Studies have shown that those three ship types could experience the most criticality for power to enable maneuverability in adverse conditions. Views have been expressed by IMO member states that further consideration for other ship types should be also performed.

The guidelines apply to ships of 20,000 DWT and above. The main reason behind this limitation is that a systematic evaluation of the required standard environmental conditions for ships with deadweight less than 20,000 DWT has not yet been completed. The IMO MEPC is currently reviewing relevant submitted proposals, with an aim to approve an agreed methodology that addresses the issue.

The current methodologies for estimating the minimum power are based on two assessment levels.

Assessment Level 1 – Minimum Power Lines Assessment

A simple approach that involves calculation of the required minimum propulsion power as a function of ship DWT.

Assessment Level 2 – Simplified Assessment

A mathematically complex assessment based on a ship’s actual data including hull form, propeller, rudder design and engine characteristics, consisting of two key steps:

1. Definition of the required advance speed in head wind and waves, ensuring course-keeping in all wave and wind directions.
2. Assessment of whether the installed power is sufficient to achieve the above required advance speed.

The Level 2 assessment requires the determination of wave added resistance through model tests in regular waves. Empirical formulae are also referenced, although not directly specified.

The application of IMO interim guidelines for MPP assessment has been extended into EEDI Phase 2. However, as of now they remain in interim form despite dedicated efforts aiming to finalize the document. The IMO Marine Environment Protection Committee (MEPC) noted that the EEDI Phase 3 implementation date is approaching and margins to reduce installed power to satisfy the EEDI requirements for certain ships' DWT segments have reached their limit. The weather conditions and ship advance speed for the Level 2 assessment are being examined once more together with the possible technical implications imposed by torque limitation due to heavy running of the propeller under actual navigational scenarios (IMO, 2019).

For additional details on the EEDI and MPP requirements, refer to the ABS Regulatory Debrief on EEDI Phase 3 Compliance for Large Bulk Carriers and Tankers.

DESIGN CHALLENGES WITH EEDI AND MPP

The EEDI is a goal-based technical standard to reduce the carbon dioxide (CO₂) emissions from shipping industry. To improve a ship's EEDI, innovative technologies like hull form optimization, air lubrication, energy saving devices or use of alternative fuels can be considered. In addition, the most effective way to reduce the EEDI rating is to reduce the ship's service speed. Reducing ship speed in terms of design efficiency will however result in reducing installed main engine Maximum Continuous Rating (MCR). Therefore, to ensure safe maneuvering in adverse conditions, the Minimum Propulsion Power requirement was introduced to the EEDI regulations.

As a result of the conflicting nature of the EEDI and MPP requirements the engine selection for large tankers, bulk carriers and combination carriers have become a design challenge. The extensive case studies undertaken by the EU research project SHOPERA (MEPC 70/INF.33) and similar studies in Japan for bulk carriers and tankers indicate that it could be difficult to simultaneously satisfy both MPP and EEDI Phase 2 requirements starting in 2020, especially when the added wave resistance is not accurately estimated for minimum propulsion power calculations. In this regard, the ability to accurately estimate the added wave resistance becomes a critical component for the ship to be verified compliant with MARPOL Annex VI, Chapter 4 and issued an International Energy Efficiency Certificate (IEEC).

An example of MPP Level 2 assessment of a tanker (VLCC) is shown in Figure 1. The added wave resistance of the tanker is estimated from model test (Exp), Computational Fluid Dynamics (CFD) and ABS RAW, a simplified method based on ISO 15016 D.3. In this exercise, the main engine MCR has been reduced to meet the requirements of EEDI Phase 2. It demonstrates that the required brake power of the tanker with an over-conservative prediction of the added resistance (labeled as Other Software) is on the border of engine load limit, which indicates the MPP assessment may fail.

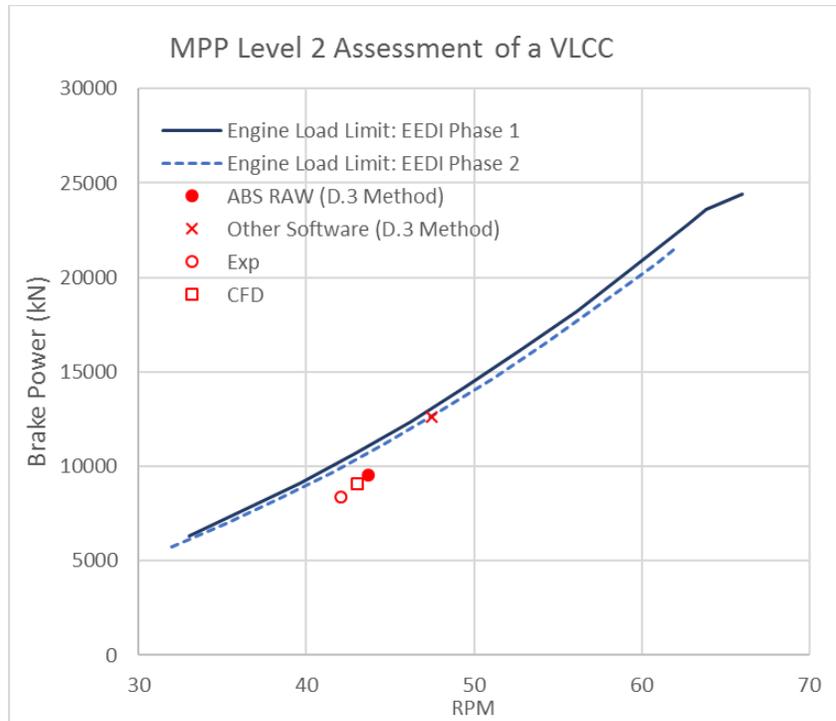


Figure 1: An Example of MPP Level 2 Assessment of a Tanker (VLCC)

Further efforts to validate numerical methods for accurate assessment of added resistance and minimum propulsion power are introduced below.

Joint Industry Project on Added Resistance

A joint industry project on added resistance was organized by Seoul National University (SNU) with participants from major Korean shipyards and Classification societies (2016-2019). Each participant contributed to the project providing independent numerical analysis of added resistance using the software of each organization.

The main objective of the project was to validate numerical methods and construct an experimental database with an aim to improve the added resistance and ship operation efficiency for hull form design. As part of the project, added resistance model tests were conducted at the SNU towing tank and SSPA model basin for the four vessel types:

- VLCC
- Bulk Carrier
- LNG Carrier
- Container Carrier

A comparative study of the added resistance was performed. The added resistances from the resistance tests at the SNU towing tank and free running tests at the SSPA model basin were compared with numerical results including the panel method NLOAD3D (ABS), WISH (SNU), and the CFD software Star-CCM+. Further details on the comparative study of the project are presented by D-M Park et al. (2019) and J-H Lee (2020).

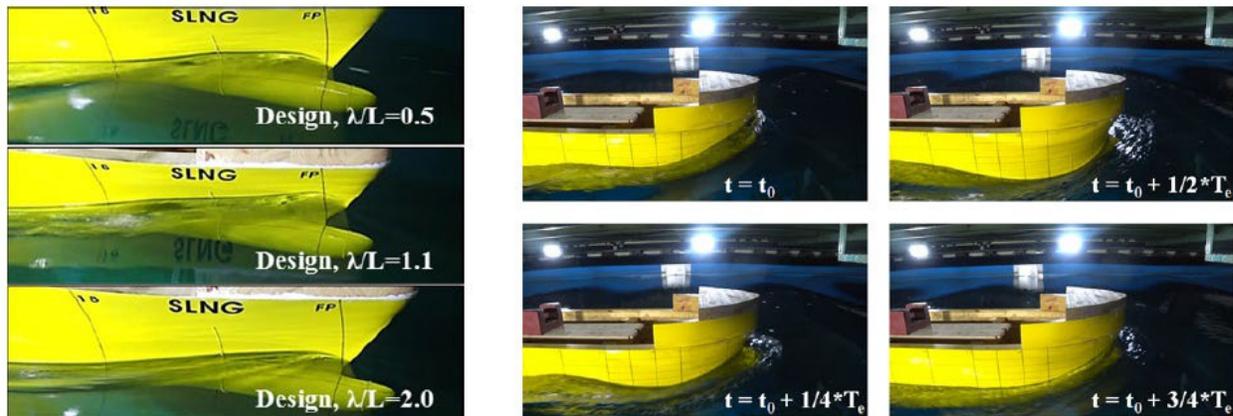


Figure 2: Added Resistance Model Tests at SNU Towing Tank, taken from the SNU JIP Final Report (2020). Left: 175K S-LNG carrier. Right: K-SUPRAMAX Bulk Carrier

Joint Development Projects on Added Resistance and Minimum Engine Power

ABS conducted joint development projects with Korean shipyards (2019-2020) to closely investigate the sensitivity of model test procedures and numerical methods on the prediction of added resistance and its impact on the Minimum Propulsive Power Level 2 assessment.

Resistance tests in waves on tankers and bulk carrier designs of various sizes were carried out and compared with numerical methods. Figure 3 illustrates that the ABS RAW software, a simplified method based on the ISO 15016 D.3, is reasonably conservative compared to the model test and CFD method. The other software, which is available in industry, also follows the principles of the D.3 method but seems too conservative compared to other methods. It is noted that the practical manner of interpretation and implementation of the D.3 method may lead to the very different results.

Under the projects, the Minimum Propulsion Power Level 2 assessments were conducted for the tested vessels, as shown in Figure 4. All the vessels pass the Level 2 requirement of $P_{Breq}/P_{BLD} < 1$ based on added resistance results from model test, CFD/panel method and ABS RAW software, while many vessels do not pass the Level 2 by use of the other software.

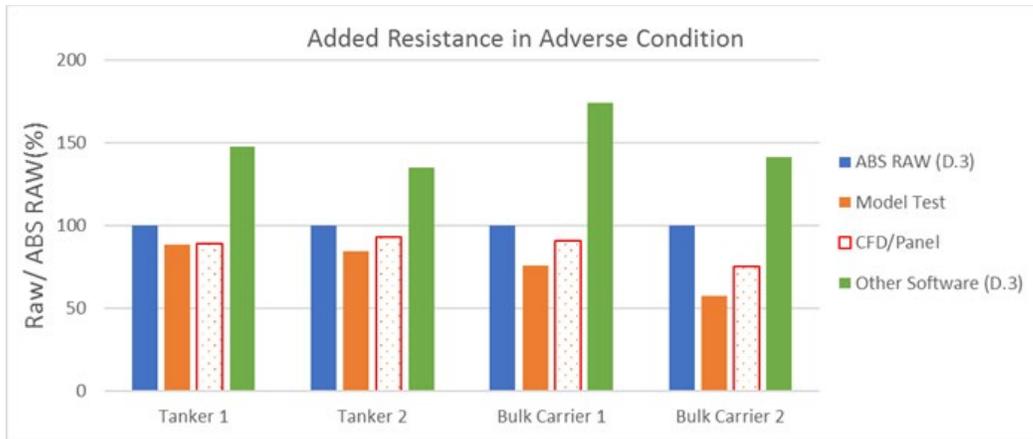


Figure 3: Added Resistance in Adverse Conditions

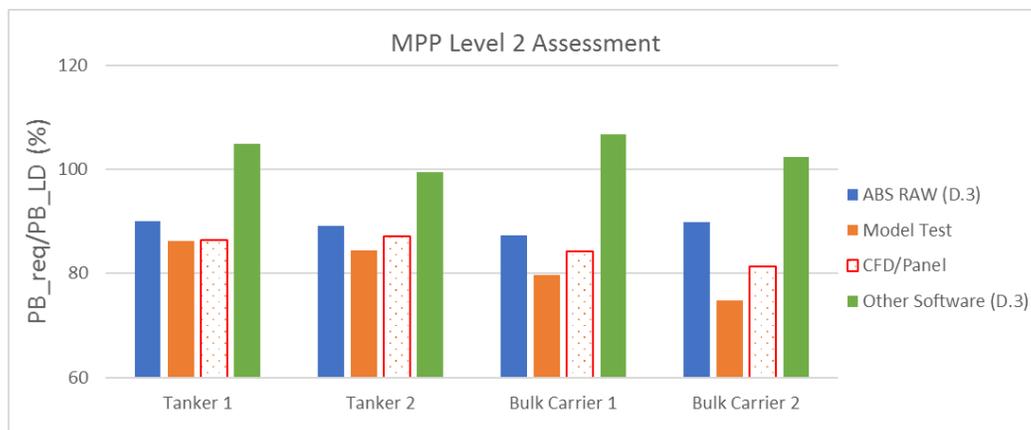


Figure 4: MPP Level 2 Assessment

INDUSTRY PRACTICES FOR PREDICTION OF ADDED RESISTANCE

ITTC Recommended Procedures and Guidelines 7.5-02-07-02-8 describes the prediction methods for the added resistance, as given in Table 1.

Simplified Method

According to MEPC.1/Circ.850/Rev.2 (2017), when seakeeping model tests are not available, the quadratic transfer function of the added resistance may be obtained from an equivalent method verified by the Administration. The quadratic transfer function of the added resistance may be calculated from the simplified methods described in the International Standard ISO 15016:2015, Ships And Marine Technology - Guidelines For The Assessment Of Speed And Power Performance By Analysis Of Speed Trial Data (2015).

Table 1: Prediction Method for Added Resistance (ITTC 7.5-02-07-02-8)

Type of Methods		Slender-body Theory	3D Panel Method		CFD	Experiments
			Frequency Domain	Time Domain		
ITTC Reference Procedures		7.5-02-07-02.5 7.5-04-01-01.2		7.5-03-02-03	7.5-02-07-02.1	
Approach		2D Strip Method	Green Function		Euler Equation Based	Captive Test Regular or irregular wave
		Enhanced Unified Theory EUT	Rankine Panel Method		Navier-Stokes Equation Based	Free sailing Regular or irregular wave
Formulation	Far-field Method	Maruo's Formula	Momentum Conservation Method		None	None
	Near-field Method	None	Direct Pressure Integration Method		Direct Pressure / Shear Stress Integration	Total Force Measurements
	Short-wave Approximation	NMRI Formula	NMRI formula can replace diffraction components		No need	No need
Fidelity		Low	Good		Excellent	Excellent
Typical requirements: Hardware; Time		Personal Computer; Minutes	Computer Cluster or PC; Hours-days		Cluster; Days	Seakeeping basin; Days

ISO 15016 D.2 Method (STAWAVE-2)

The D.2 method is an empirical method to approximate the added resistance using the main parameters such as ship dimensions and speed. The empirical method includes the added resistance due to ship motions and the added resistance due to wave reflection.

Further details on the description of added resistance are given in ISO 15016 D.2. The application of D.2 method is limited to the waves in the bow section to $\pm 45^\circ$ off bow waves which are treated as head waves for this method. The D.2 method also has the following application limits:

$$L_{PP} > 75(m)$$

$$4.0 < \frac{L_{PP}}{B} < 9.0$$

$$2.2 < \frac{B}{T_M} < 9.0$$

$$0.1 < \frac{U}{\sqrt{gL_{PP}}} < 0.3$$

$$0.5 < C_B < 0.9$$

ISO 15016 D.3 Method (ABS RAW)

The D.3 method is a theoretical or semi-empirical method to calculate the added resistance based on the slender body theory using ship dimensions and waterline geometry. The D.3 method includes the added resistance due to ship motions and added resistance due to wave reflection.

Further details on the description of added resistance are given in ISO 15016 D.3. The D.3 method is applicable to the ship types such as container carriers, bulk carriers, tankers or ro-ro cargo ships whose length is more than 190 meters. According to the ABS experience, the application of the D.3 method to a 22 K tanker with a ship length of 162m was satisfactory compared to the model test data. For the application of the D.3 method to vessels whose length is less than 190m, additional evaluation would be recommended including comparison with results by model test, CFD and panel method.

For sea trial analysis, the D.2 method has been widely used for the prediction of added resistance. As the D.2 method is a simplified empirical method, a limited accuracy is expected. Figure 5 shows the added resistance of a tanker indicating the D.3 method is much closer to the model test results. For accurate sea trial analysis, the D.3 method for added resistance would be recommended.

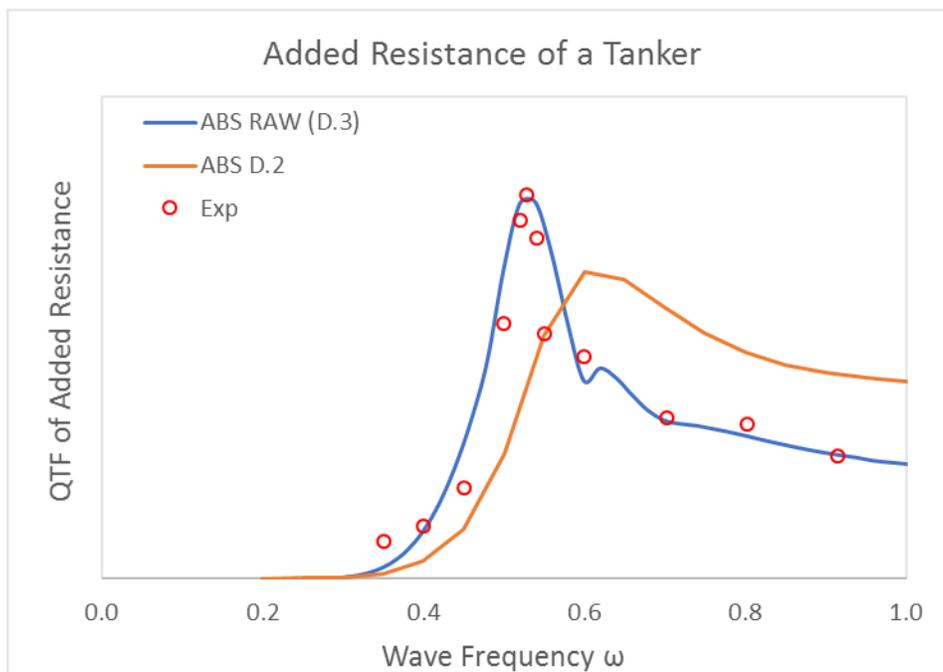


Figure 5: Added Resistance of a Tanker: D.2 vs. D.3 Method

Panel Method

Over the last few decades, seakeeping analysis has advanced from the linear frequency-domain 2D method to the nonlinear time-domain 3D panel method. Considering the nonlinear hydrostatic restoring and Froude-Krylov forces, the weakly-nonlinear panel method has been widely used as an efficient and practical tool for ship design.

NLOAD3D is the ABS in-house seakeeping and maneuvering analysis program based on the weakly-nonlinear time-domain 3D Rankine panel methods. A sample of hydro panel model of a bulk carrier is shown in Figure 6. The added resistance of the K-SUPRAMAX bulk carrier used in the study of the Korean Joint Industry Project is shown in Figure 7. The results of the NLOAD3D look reasonably comparable to the model test results. For the panel method, due consideration is to be given to the panel size in order to resolve the waves with short wavelength, especially near the bow area. An accurate modeling of bow geometry would be more important than stern geometry for the calculation of added resistance in head waves.

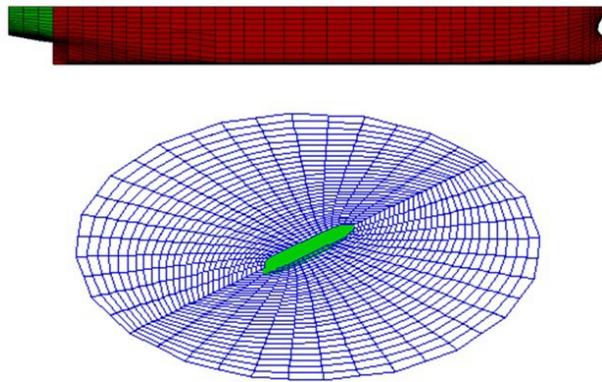


Figure 6: Sample Hydro Panel Model

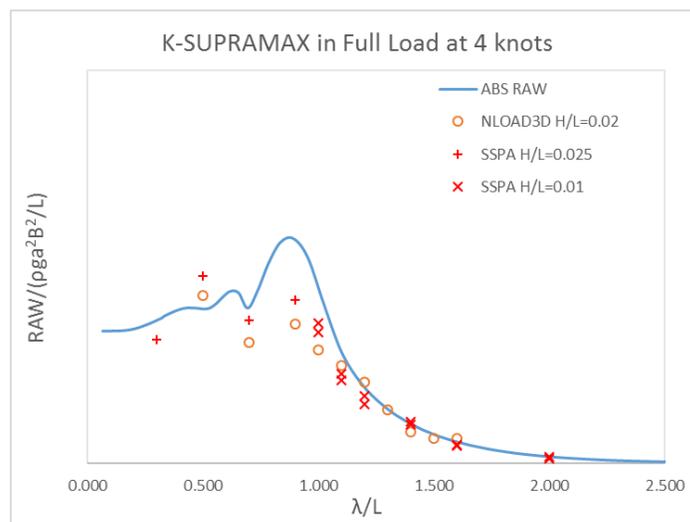


Figure 7: Added Resistance of a Bulk Carrier

CFD

CFD is a powerful numerical approach to calculate the added resistance of ships. The nonlinear free surface waves can be captured by a two-phase fluid model using the volume of fluid (VOF) or the level set method. Pitch motion is critical to the added resistance of ships in waves. The ship motions can be solved by the time integration of 6-DOF equations of motion using the Dynamic Fluid Body Interaction (DFBI) model or the overset grid method.

For accurate modeling of incident waves, the 5th-order Stokes waves are recommended. The computational domain size is to be large enough so as not to affect the flows near the ship. A typical computational domain and mesh for the simulation of added resistance is shown in Figure 8. Fine meshes are arranged near the free surface zone to resolve complex wave flows.

Due consideration is to be paid to numerical damping, which primarily depends on mesh size and time step. The numerical damping may be reduced by providing a fair resolution of mesh size and time step. The recommended practice is to use 100 cells per wavelength and 10 cells per wave height. Figure 9 shows the quadratic transfer function (QTF) of added resistance of a tanker.

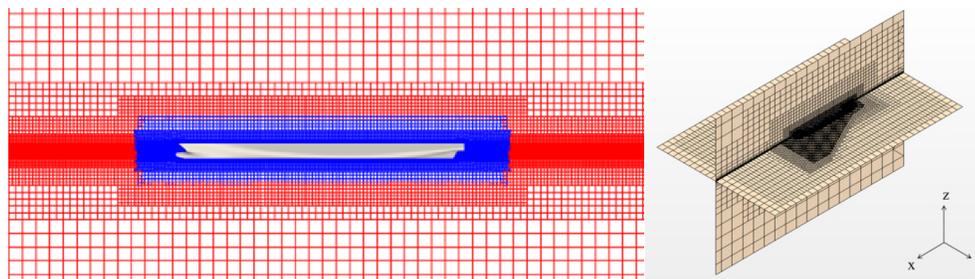


Figure 8: Example of Computational Domain and Mesh Generation

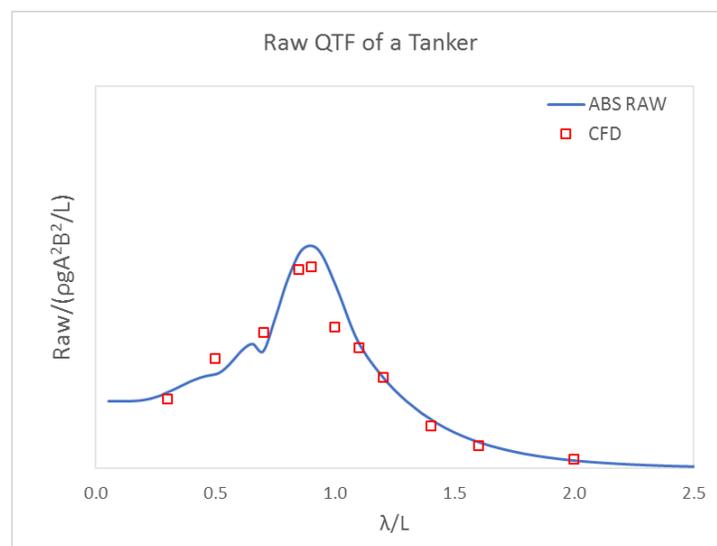


Figure 9: QTF of Added Resistance of a Tanker

Model Test

MEPC.1/Circ.850/Rev.2 (2017) recommends the model test in regular waves for added resistance per ITTC procedures:

- ITTC 7.5-02-07-02.1 (2011)
- ITTC 7.5-02-07-02.2 (2014)

The resistance test and free running test are the testing procedures commonly adopted by the model basins worldwide.

Resistance Test in Waves

The merit of this method is that the added resistance can be directly obtained through measurements. The added resistance can be estimated from the runs in still water and in waves, preferably using the same model and the same model outfit. The model may be equipped with bilge keels and rudder, but without propeller. In this test, the model is towed by towing carriage at a constant speed. The interferences of towing apparatus on the motions of the model are to be minimized.

A soft-mooring system is an attractive towing method of connecting the model and towing carriage with mooring lines. The end of the mooring lines may be connected to soft springs, allowing the model freely to move in all six degrees. The added resistance can be measured as a towing force from the strain gauge type load cells attached to the mooring lines.

Free Running Test in Waves

According to the ITTC 7.5-02-07-02.1, the free running test is a preferred method for seakeeping experiments. In the free running tests, the thrust and rpm are directly measured from the propulsion dynamometer fitted to the model propeller. The added thrust can be estimated from the free running tests in still water and in waves, preferably using the same model and the same model outfit.

The self-propelled model is to be fully equipped with bilge keels, rudder and propeller running at a self-propulsion point to maintain the predefined speed in waves. Preliminary tests may be necessary to adjust the propeller rpm in order to reach the desired speed in still water and in waves. Alternatively, the rpm is to be automatically controlled by an auto-pilot system with rudder control to maintain the speed and heading. A typical self-propelled model for the free running test is shown in Figure 10.



Figure 10: A Self-Propelled Model of a Container Carrier

The added resistances of a tanker are shown in Figure 11, comparing the resistance tests (soft mooring) and free running tests conducted at towing tank and ocean basin. While the measured and calculated results seem quite scattered, the added resistance from the soft mooring tests appear to be closer to the ABS RAW D.3 method.

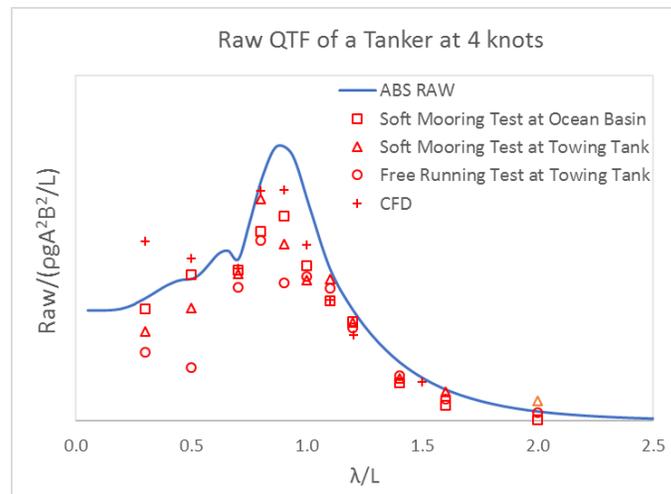


Figure 11: Added Resistance of a Tanker

ABS SOFTWARE AND SERVICES

ABS RAW Software

According to the MEPC.1/Circ.850/Rev.2 guidelines, the added resistance can be obtained from the model tests or from an equivalent method verified by the Administration. At early design stages, however, conducting model tests to estimate the added resistance can be impractical due to tight design schedule.

To support ship designers, ABS released a software, ABS RAW, based on the guidelines in ISO 15016:2015 D.3. This software has been validated with extensive model tests from the industry collaborative projects. ABS RAW provides an Excel based calculation routine for added resistance based on principal dimensions and waterline geometry, as shown in Figure 12. The software is available to ship owners and shipyards upon request.

Block 1: Vessel Information	
Vessel Type	Bulk Carrier
Loading Condition	Full
Ship Length, Lpp (m)	194.5
Ship Breadth, B (m)	32.26
Summer Load Line Draft, moulded, Tm (m)	13.3
Block Coefficient, Cb	0.876
Pitch Radius of Gyration Kyy/Lpp	0.2331
Ship Speed Vs (knots)	5.327
Block 2: Wave Conditions	
Wave spectrum	JONSWAP
Significant wave Height Hs (m)	4
Peak Wave Period Tp (7s to 15s)	15
Block 3: Constants	
Density of Seawater ρ (kg/m³)	1025.18
Gravity g (m/s²)	9.81

Figure 12: Sample Input of ABS RAW software

ABS Services

In addition to the EEDI and MPP verification, ABS offers a variety of related services including:

- GHG Rating Improvement, including confirmation of minimum propulsion power
- Energy Efficiency Technology Powering Performance Assessment, using in-service measurements prior and after installation
- Benchmarking at design and operational level
- Hull and Propeller Performance Monitoring
- Evaluation of Engine Power Limitation (EPL) options
- Pathways to Carbon Intensity Reduction
- New construction technical specification improvement
- Speed-Power-Consumption reference values in weather

For more information, visit www.eagle.org

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