New Guidelines for Speed/Power Trials
Level playing field established for IMO EEDI

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ABSTRACT
The speed/power characteristics of ships have always been at the core of ship design. To prove contractually agreed values, speed trials are conducted by the yard prior to delivery of the ship to the owner. In the past schedule integrity of the vessel was often the most important factor for the speed requirement. Today, owners and operators are keen to reduce fuel consumption to decrease operational costs. So far a variety of methods for conducting and analysing speed/power trials have been used by shipyards. With the assistance of the Sea Trial Analysis-Joint Industry Project (STA-JIP) and ITTC, the new IMO EEDI rules to reduce CO2 emissions have resulted in clear, pragmatic and transparent guidelines for the reliable speed/power assessment of ships worldwide.

BACKGROUND
In 1929 Dutch shipowners in close co-operation with the Royal Netherlands Navy and Shell founded the independent Netherlands Ship Model Basin (NSMB), now known as MARIN and started to construct the Deep Water Basin in Wageningen to make sure that new ships would meet the speed/power performance expected. At that time most shipping companies designed their own ships and determined speed and shaft power over the "measured mile" during delivery trials. Since then the shipping and shipbuilding industry has dramatically changed. Ship owning and ship operation have been separated and yards became completely responsible for design, model testing, engineering, construction and even for the conduct and analysis of delivery/acceptance trials.

Figure 1. COSCO NAPOLI was subjected to Speed/Power Trials compliant with the STA industry standard (Courtesy: ER-Schiffahrt)

Speed/power trials are conducted to establish the performance of the vessel at design draught and trim under stipulated weather conditions, usually deepwater, no wind and no waves. As the conditions encountered during the trials often deviate from the contract conditions, corrections are applied during the analysis and reporting of the trial results. In the past, institutes such as BSRA, NSMB, SNAME and ITTC published methods for conducting and analysing speed/power trials. Shipyards "randomly" selected and developed their own "yard standard" from these methods. In 2002, the International Standard Organisation published ISO 15016, which was a cumbersome analysis method based on a wide choice of outdated correction methods and empirical data. The application of this standard led to adverse experiences and to several shipowners taking delivery of ships which were unable to meet the required schedule and that burnt significantly more fuel than anticipated. In some cases the "sea margin" of 15% on power was already consumed by the new ship in calm water.

STA-JIP

This was the reason why Shell, Nedlloyd and MARIN decided to initiate the STA-JIP in 2004. STA aimed to develop transparent, practical and reliable ***Best Practice*** for conducting and analysing speed/power trials utilising present day knowledge and methods for modern ships. The speed/power trial analysis and reporting should be completed on board within one hour after completing the speed runs. Only then can additional tests be initiated if unsatisfactory results are obtained.

Several leading shipowners from Germany, Greece, Japan, Denmark, the Netherlands, Norway and Sweden joined the STA-JIP. First of all, the speed/power results of about 30 recently delivered vessels from these owners were reanalysed. This ***gap-analysis*** showed the need to improve the basic trial procedures and method of analysis, as well as the correction methods for wind, waves and shallow water. Particular attention was requested for the conversion of trial results at ballast draught compared to the (contract) design draught. Once the STA-JIP found its bearing and showed results from the case studies, more owners and all the major yards from Korea joined this project, which aimed to assess the ship speed within 0.1 knot and the associated shaft power within 2%. To achieve these goals MARIN worked in close co-operation with all participants for three years. The most important developments are highlighted below.

Conduct & analysis method

The two basic parameters to be measured during the trials are ship speed and shaft power. By determining these parameters at different engine power settings and correcting these for non-ideal circumstances, the speed/power relation for the ship at trial draught and trim can be established.
As illustrated by Figure 2, the speed and shaft torque of a vessel in realistic weather conditions is varying constantly, both with wave frequency and with lower frequencies. It is obvious that reliable measurements and analysis methods are required and at the same time, strict limitations have to be taken into consideration during the speed/power trials such as the minimum water depth, maximum wave heights and maximum wind speed.

Figure 2; Speed through water and over ground and shaft torque measured on an 1800 TEU container vessel in 4 m significant wave height (Courtesy; Vroon)

Although the speed log is one of the oldest sensors on board ships, it is still one of the most inaccurate instruments and it does not give the speed through water with an acceptable accuracy. The D-GPS however, is capable of deriving the speed over ground. To eliminate the current from the speed over ground, the results of double runs (i.e. speed runs on reciprocal courses), can be averaged according to the "mean of means" method also referred to as "Pascal's triangle", which was already presented by Van Lammeren in 1939 and also recommended by the Principles of Naval Architecture [1]. To account

for time varying currents such as tidal currents, two or more double runs are required for the same power setting.
The “mean of means” is applied after correcting the measured speed/power points for wind, waves and other deviations from ideal conditions except the conversion from the (ballast) trial draught to the contract design draught. All corrections for non-ideal conditions are expressed in shaft power corrections (except for shallow water) and the propeller efficiency is corrected for non-ideal loads by use of the results of load-variation model tests.

The speed over ground is derived from the end-positions of the speed run over a minimum measurement duration of 10 minutes. Each double run consists of a speed run in head waves and a counter run in following waves. The reason for this is that practical wave corrections are only available for those courses and rolling, steering and course deviations should be avoided.

The above approach is referred to as the Direct Power Method and is far more transparent, reliable and practical than the use of the propeller open water diagram proposed by Tanaguchi & Tamura in 1966 [2] and adopted by ISO 15016 (2002) [3] which is based on several physical assumptions, fairing and curve fitting. In Figure 3 a flow diagram of the STA Best Practice for speed/power trial analysis (2006) is presented.

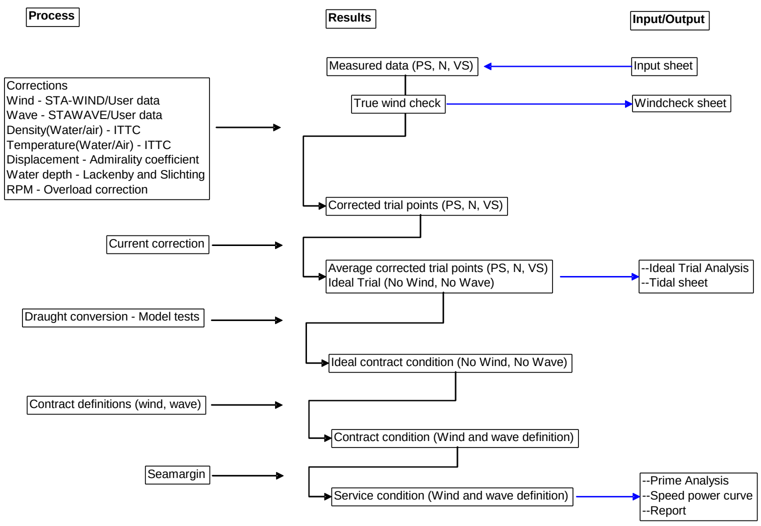


Figure 3; Flow diagram of the STA Analysis

Wind correction

The wind drag on ships increases quadratically with the relative wind speed and therefore the actual encountered wind speed and direction should be measured as accurately as possible. Wind speed read from the anemometer on top of the wheelhouse should be treated with care as the wheelhouse normally generates over-speed at this location. For some wind directions the anemometer may be shielded by masts, funnels or cargo. To minimise these effects the wind vector is averaged over the results of the two counter runs in one double run set as illustrated by Figure 4.

As the ship navigates in the boundary layer of the wind over the sea, it is important to take the wind velocity profile into account. Wind speed is normally defined as the average velocity at a height of 10 meters above the surface. Wind drag coefficients are also normally derived in a wind profile defining the wind, speed at 10 meter. For this reason the wind measured by the anemometer has to be corrected for the height of this sensor. When the anemometer is located 50 meter above water for example, this height correction results in a 21% reduction in wind speed and 46% in wind load. When the forward speed of the ship is included, the effect on the wind load can be even larger.

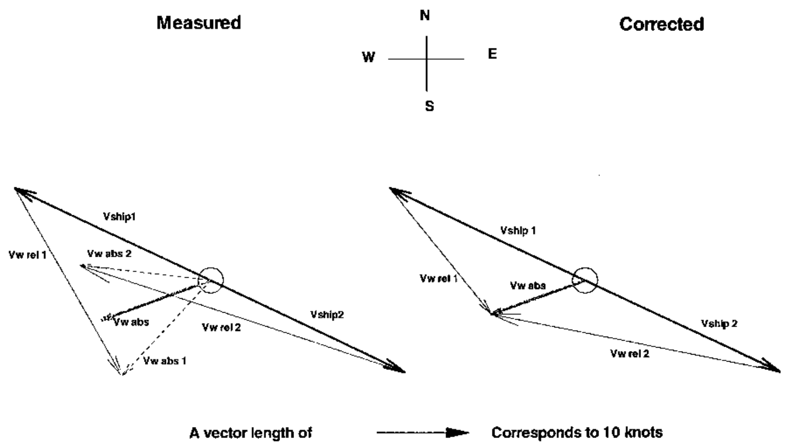


Figure 4; Averaging of measured wind vectors over two counter runs to derive the true wind vector

Wind drag coefficients for ships have been published by many authors in the past, however modern vessels are much larger and have a different geometry than ships used in well-known wind resistance publications. Therefore, it is important to use recent ship type and size specific data derived from proper wind tunnel measurements or validated computational tools such as LES-RANS CFD. For containerships it is crucial to distinguish the wind drag in ballast condition without containers on deck but while taking into account the lashing bridges (which are exposed to wind during trials) and the design draught case where the vessel is loaded with containers. Remarkably the wind resistance coefficient of the loaded vessel is normally smaller as the full container pack provides a better flow shape than the wheelhouse and lashing bridges!

The STA-JIP collected systematic wind tunnel data sets for various ship types and loading conditions. Also conducted extensive CFD analysis have been conducted to correlate with wind tunnel data to arrive at a solid understanding of wind drag and to establish extensive empirical data sets for wind drag correction.

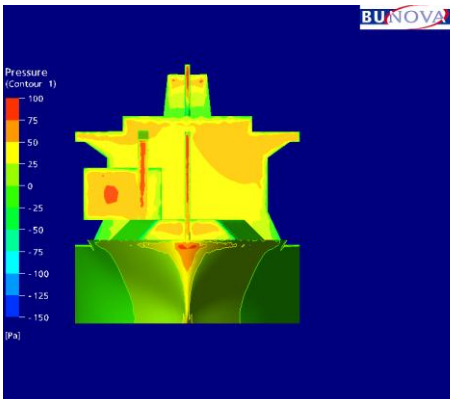


Figure 5; Wind drag pressures on a membrane type LNG carrier computed with RANS CFD for STA (BUNOVA 2005)

Wave correction

Even within the trial limits for wave height (significant wave height below 1.5% of ship length), the added resistance due to waves can be a substantial part of the required shaft power. The added resistance in waves increases quadratically with wave height and thus even in low sea states the wave correction method should provide an accurate prediction of the added resistance for the specific ship and the actual encountered wind driven sea and swell conditions. At the same time, the method should be practical requiring limited input; today, many yards refuse to deliver the body plan to the shipowner and the encountered wave spectrum is not normally measured.

Model test results in regular and irregular head waves for ten ships types in full load and ballast and at different speeds, were compared by MARIN against predictions in a variety of published methods (amongst others by ISO 15016:2002) and widely used wave correction methods using the ship specific geometry and the measured wave spectra. As illustrated by Figure 6 the results were shockingly different! Therefore the STA-JIP decided that a new and more reliable method for trial wave corrections was required.

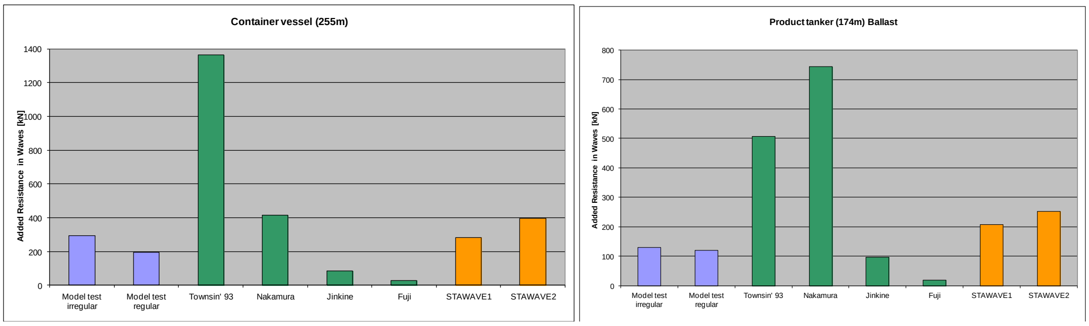


Figure 6; Commonly used empirical wave correction methods (green) compared with model test results (purple) and the new STAwave computational methods (orange) for a 174 m tanker and a 255 m container vessel in irregular head waves.

The added resistance in waves originates from two wave systems [4]; firstly the reflection of short waves on the hull and secondly, the wave induced ship motions i.e. heave and pitch. The first component is dominant in short waves, the second component contributes if the wave lengths are similar to the ship length (Figure 7). STA used the “horses for courses” approach; STAwave-1 for reflecting irregular head waves and STAwave-2 for head waves in which the vessel is pitching and heaving. If desired, other conditions model test results for the specific ship geometry can be used.

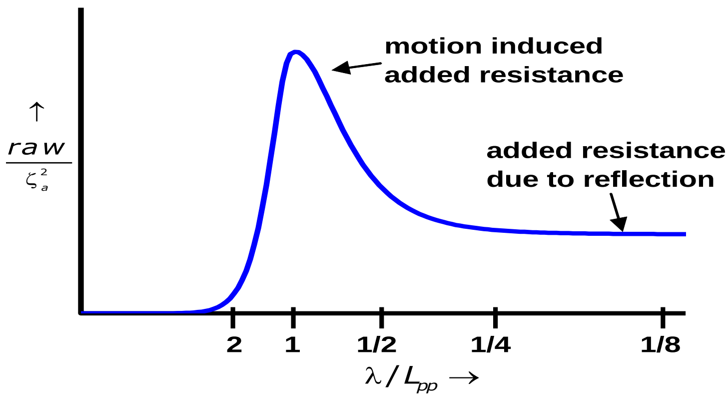


Figure 7; Added resistance in waves as function of wave length over ship length.

The STAwave-1 method is based on the fact that for today’s large ships the head waves encountered in trial conditions are normally short compared to ship length and speed. The added resistance due to the reflection of those short head waves is mainly dependent on the shape of the waterline in the bow region. Ship displacement, draught, trim and speed play a secondary role. Actually the dominating reflection part in added resistance is a component of the second order wave forces which can be analytically found from integration over the waterline geometry [5]. For ship shapes in head waves this analytical expression was simplified for practicality to:

$$\bar{R}_{aw} = -\frac{1}{16}\rho g H_s^2 B \sqrt{\frac{B}{L_b}}$$

Where:

B = Beam of the vessel on the waterline[m]

L_b = Distance of the bow to 95% of maximum beam on the waterline [m]

H_s = Significant wave height [m]

The above expression is particularly practical for speed/power trials as only the ships beam, the length of the bow section and the significant wave height are required as input. No other ship particulars such as parametric coefficients or bluntness factors nor ship speed or wave spectrum are required. It is simply assumed that the asymptotic short wave value of the transfer function extends over the complete range of wave frequencies and thus that the vessel is not heaving and pitching, which can be easily checked during trials.

For small and medium sized vessels or in case long swells are encountered during the trials, the vessel actually will heave and pitch and those motions will contribute to the overall resistance. For this purpose STAwave-2 was developed. This is an empirical statistical method utilising seakeeping model test results from 200 ships. The transfer function of the added resistance in head waves is parameterised to a function of seven input quantities resembling ship geometry, ship speed and wave spectrum. A spectrum shape (Pierson-Moskowitz (PM) for seas and Jonswap for swells) is assumed in this method but both significant wave height and mean period have to be specified.

Both STAwave methods were validated with dedicated model tests for a Panamax containership and an Aframax tanker at scale 1:38 and 1:43 respectively in MARIN's Seakeeping and Manoeuvring Basin. It should be noted that reliable added resistance measurements at model scale requires large models (typically 6 – 8 m.), a dedicated test setup and sufficient run length in the basin. Only the largest seakeeping basins in the world offer this capability. As illustrated by Figure 8 both STAwave-1 and STAwave-2 show an acceptable agreement with the model test results and are far more reliable than existing empirical methods shown in Figure 6.

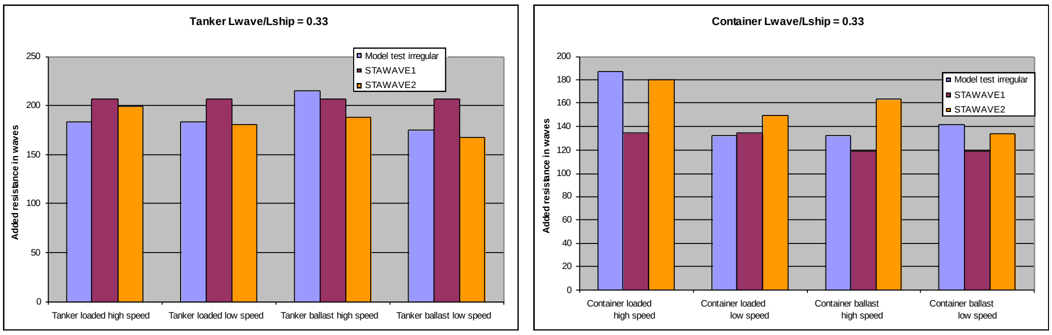


Figure 8; Added resistance in irregular head waves computed by STAwave 1 & 2 compared with results of large model tests for different speeds and loading conditions.

As reliable wave corrections can be made for head waves and if the added resistance in following waves is negligible for normal trial conditions, speed runs in head waves and following waves need to be carried out. For wave directions within the +/- 45 degr. bow sector STAwave for head waves is applied. However, if yard and owner want speed/power trials in other circumstances, they may conduct dedicated seakeeping model tests and measure the encountered wave spectrum during the speed/power tests. Measurement of the encountered wave spectrum is also required in case non-benign sea conditions are encountered during the speed/power trials.

Conversion from ballast draught to design draught

As several ship types such as containerships and dry cargo vessels, due to lack of cargo, cannot be subjected to speed trials at their design draught and trim during delivery trials, results of these trials have to be converted to the contractual design draught and trim conditions. This conversion is then based on the difference of calm water model test results for the trial condition and the design condition. This has proven to be one of the largest causes of deviations and discrepancies in the results of delivery speed trials.

Model test results are always extrapolated to full scale on the basis of scaling laws, as well as "correlation coefficients". These statistical correlation coefficients relate the scaled-up model test power to the predicted power for the actual speed/power trials with that vessel. For a model basin with a sufficiently large trial database for the specific ship type and size, this practice has proven that it is able to deliver power predictions with acceptable accuracy over the years. Model test prediction accuracy is thus dependent on the experience of the model basin and consequently the availability of accurate speed/power trial data. For several ship types however, design draught trial results is scarce. This is a particular problem for relatively new ship types, where data related to modern speed ranges and recent sizes is often missing.

The STA-JIP conducted dedicated speed/power trials on three container vessels amongst others, in the range of 6000 to 14000 TEU at design draught/trim (Figure 9) and compared the results with the results of the original delivery trials, which were also analysed according to STA. For two vessels deviations of more than 10% in shaft power were found. If considering fuel consumption of 240 tons/day this means an excess fuel consumption of 24 tons/day over the lifetime of the vessel! For this reason the STA-JIP has formulated strict guidelines for this ballast draught-design draught conversion of speed/power trial results as well as for the extrapolation of model test results towards full scale. Such guidelines are lacking in ISO 15016 and other speed/power trial methods.

Figure 9; 14000 TEU MSC SAVONA was subjected to speed/power trials by the STA Group in both ballast draught and design draught (Courtesy: Claus Peter Offen)

STA GROUP

After three years of R&D work and collecting practical experience with owners and yards, the STA-JIP reached consensus on the new method in July 2006 and delivered the "Best Practice for Speed/Power Trials" [6] and [7] comprising:

- "Recommended Practice for Speed/Power Trials" (how to execute speed/power trials)
- "Recommended Analysis of Speed/Power Trials"(how to convert to contract condition)
- QSTAP; software package for speed/power trial analysis and reporting on board.

On behalf of the owners participating in STA, the new industry standard was applied by MARIN during the delivery trials of several different ship types including general cargo ship, two LNG carriers, a car carrier, tanker and three container vessels, to make sure the new method was reliable. Results were shared with all the STA members. The participating companies then started to use STA themselves in their newbuilding projects.

At the same time, the members decided to continue as the STA Group to exchange user experiences, initiate research and to guide new developments. Over the years new owners, operators and yards but also model test basins and class societies joined the STA Group, which now comprises 35 organisations to date (Figure 10). The STA Group also remains open to new members.

Figure 10; STA Group Members

IMO-EEDI

To reduce CO2 emissions by shipping over the last few years IMO MEPC has developed the Energy Efficiency Design Index (EEDI) for new ships. The EEDI basically calculates the amount of CO2 emission per ton-mile. In the formulation of the EEDI the ship’s speed is a basic parameter. But a decision had to be taken on the method to derive the reference speed of the ship. Initially, Asian countries proposed ISO 15016:2002 for this purpose. Then in April 2011 Norway submitted a proposal to IMO to reconsider this matter on the basis of a MARIN report showing the deviations between STA and ISO 15016:2002 (see Figure 11), which leads to large differences in the EEDI for various ship types [8]. The report also explained the possibility of “free” interpretation of the outdated methods within the ISO methodology.

Subsequently the International Towing Tank Conference (ITTC) offered to formulate new guidelines for speed/power trials by June 2012, taking into account the STA achievements and this was accepted by IMO MEPC.

	Container vessel, 14000 TEU	*140,500 m³ LNG Carrier*	*Container vessel, 7200 TEU*		*160 m Reefer cargo carrier*
Loading condition on trial	Ballast	Ballast	Ballast	Laden	Ballast
Speed difference between correction methods	0.68 knots	0.40 knots	-0.07 knots	0.12 knots	1.02 knots
EEDI based on ISO 15016 [g-CO2 / ton mile]	***14.662***	***11.826***	***16.514***	***17.219***	***17.559***
EEDI based on STA [g-CO2 / ton mile]	***15.072***	***12.072***	***16.470***	***17.302***	***18.367***

Figure 11; Difference of ISO 15016 and STA analysis methods and effect on EEDI for several ships (from [8]).

In 2012 the 27th ITTC Committee for Performance of Ships in Service closely co-operated with the STA Group to review and improve the speed/power trial procedures and measurements, as well as the analysis and correction methods. The IMO brief asked that a transparent, un-ambiguous and practical method had to be delivered which would be acceptable for all stakeholders and that could be used for both contractual agreements between yard and owner as well as for the assessment of the IMO EEDI for any new-built ship worldwide. At the same time, the results of the speed/power trials should be completely documented and traceable for the EEDI Verifier representing the flag state of the vessel.

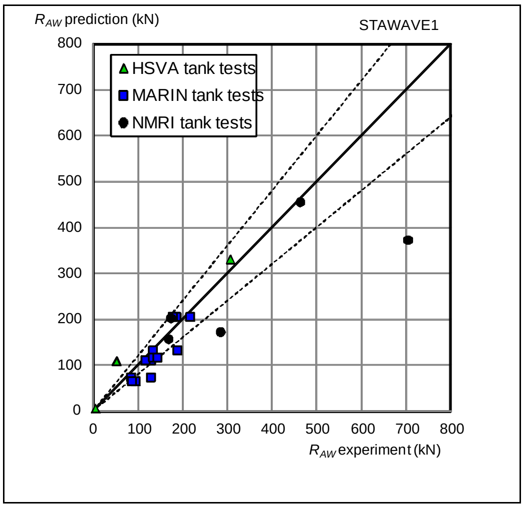
The Direct Power Method was selected by the ITTC as the basic analysis method. The required number of double runs at various power settings was specified:

- two double runs at contract power;
- two double runs at EEDI power (75% MCR);
- one double run at one other power setting between 65% and 100% of MCR.

For sister ships the programme can be reduced to one double run at contract power, EEDI power at one other power setting between 65% and 100% of MCR. In adverse environmental conditions additional double runs are required. The measurements and recording of all required signals during speed runs with a minimum duration of 10 minutes have been specified in detail in these Guidelines.

Available wave correction methods were scrutinised by ITTC. Results from STAwave-1 and STAwave-2, as well as from a method developed by NMRI in Japan [9], were verified against model test results available from the ITTC members participating. A typical result is given in Figure 12. Based on the results of this benchmark study, it was concluded that these three methods provide estimates of similar accuracy. It is worth noting that if the NMRI method is combined with specific model tests and use of the actual measured encountered wave spectrum, its results are improved. Based on this evaluation these three wave correction methods (each for specific application) were endorsed by ITTC.

The wind correction method developed by STA has been included by ITTC and the STA wind drag coefficient sets for several ship types have been accompanied with a method published by Fujiwara [10].



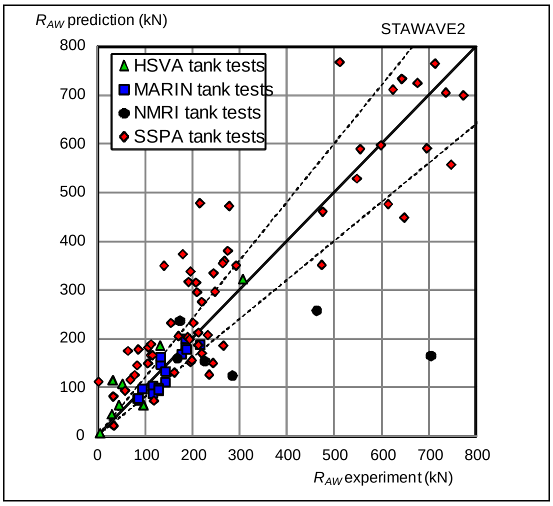


Figure 12; STAwave-1 and STAwave-2 correlated with model test results for various ship types, loading conditions and speeds in irregular head waves

The importance of the quality of model test results for the analysis of speed/power trials is now recognised by ITTC and the IMO. Strict requirements are formulated for the model test results for the trial condition, EEDI condition and contract draught and trim. It is stipulated that for all draughts and trims the same procedures and the same empirical coefficients should be used to extrapolate the model scale values to full scale. If different methods or coefficients for the various draughts are used, these should be documented in full detail including the justification by means of full-scale speed/power trial data for the specific ship type, size and loading condition.

NEW GUIDELINES

In June 2012 ITTC submitted its new "2012 Guidelines for Speed and Power Trials" to IMO MEPC 64 [11]. Part II concerns the Analysis of measured speed/power trial data and was accepted by IMO MEPC 64 in September for EEDI use. Part I concerns the Preparation and Conduct of speed/power trials and was accepted as an informative paper. The final wording of Part I will be submitted to IMO MEPC 65 in January 2013.

With the acceptance of these new 2012 Guidelines, STA, ITTC and the IMO have established a transparent, straightforward **best practice** and a **level playing field** for the delivery of new ships for all stakeholders. These new Guidelines will be used worldwide by yards, owners, vessel operators and EEDI verifiers to establish the vessel's speed from speed/power trials both for contractual purposes and for EEDI respectively.

FUTURE WORK

Although with the IMO MEPC acceptance of the 2012 ITTC Guidelines many of the original STA-JIP objectives have materialised, the STA Group will continue its activities. To avoid multiple interpretations and various software implementations, the STA is revising the QSTAP software into the new STAIMO software for analysis and reporting in full compliance with the new IMO MEPC rules. The STAIMO software will be certified and marked for authenticity checks. Subsequently the software will be distributed to all STA Group members and a web version will be made publicly available. The STA Group will also gather feedback on the use of STAIMO, organise user training and meetings, as well as support of the software. EEDI verifiers will be actively supported by STA Group.

The STA Group will continue to conduct speed/power trials on ships at design draught to compare them with the results of the delivery trials and to provide the relevant model test basins with essential feedback for their extrapolation procedures and correlation coefficients for new ship types and sizes.
In the meantime an evaluation of the trial results of a large series of sister ships is being undertaken to achieve a better understanding of the performance differences of fleets of sister ships.

The STA is also supporting the development of the new Wageningen C/D Propeller Series JIP, which measures the thrust, torque and spindle torque characteristics of a large new systematic series of Controllable Pitch Propellers and ducted CPPs.

Another task at hand is the verification and implementation of a new correction method for shallow water. The existing Lackenby method is known for the significant over-estimation of the effect of shallow water on ship speed. This problem originates from the model test data set measured by Schlichting. This data set not only includes the effect of shallow water but also the effect of the horizontal restriction due to the basin walls.
Recently a new computational approach to correct speed/power for water depth has been developed by Raven and his co-workers [12]. In 2013 this method will be validated by full-scale trials at different water depths before proposing this new method to ITTC and the IMO MEPC. This sub-project called "Shoals Power" is supported by the NML MIIP-programme and will be conducted in close co-operation between the STA Group, owners, shipyards and MARIN Trials & Monitoring.

Acknowledgement
The authors would like to thank all members of the STA Group and their co-workers for all their valuable contributions to this work.

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