Group Discussion 1
Full Scale Trials

Session Chairman: Dr. Henk van den Boom

1. PRESENTATIONS

1.1 By Dr. Henk van den Boom, Maritime Research Institute Netherlands, The Netherlands, on Improving Speed and Power Trials

Purpose of speed and power trials upon delivery:

- Verification of contractual performance,
- Service / Charter party information,
- Correlation data for model tests,
- Feed back for design.

Present situation:

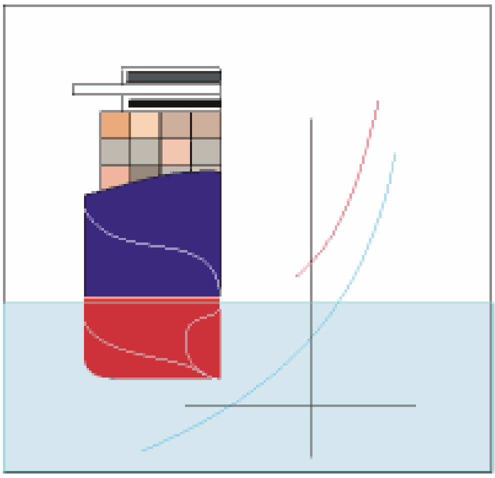
- Design, Construction and Trials responsibility of yard,
- Contractual performance is not detailed,
- Variety of trial procedures, measurements and analysis in use,
- Several vessels under perform in service.

Standards:

- Specialist Committee 23rd ITTC on Speed and Power Trials
  - Review of correction methods,
  - Uncertainty analysis measurement equipment,
- ISO 19019 (2001)
  - Guide for Planning, Carrying Out and Reporting Sea trials,
- ISO 15016 (2002)
  - Guidelines for the assessment of speed and power performance by analysis of speed trial data.

Sea Trial Analysis Joint Industry Project (JIP). Objective:

- Transparent and accurate methods for speed/power trials,
- Rational review of analysis procedures within the frame work of existing ISO standard 15016.



Scope:

1. Case study to investigate results of trials,
2. Develop Recommended Practice for Trial Procedures and Measurement,
3. Develop and improve analysis methods,
4. Develop and deliver software for on-line

analysis,

5. Demonstrate and validate new practice during trials.

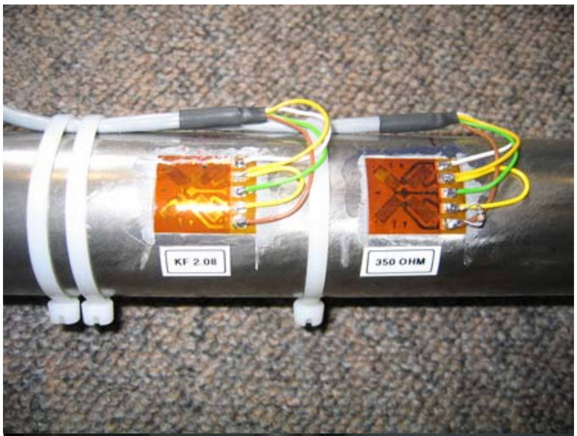
Sta-JIP Participants:

- CPO, ERS, Hapag-Lloyd, NDR, NSB, Shell, Teekay, UECC, Vroon,
- DSME, Hanjin SC, Hyundai, Samsung, STX, Sumitomo.

Trial aspects:

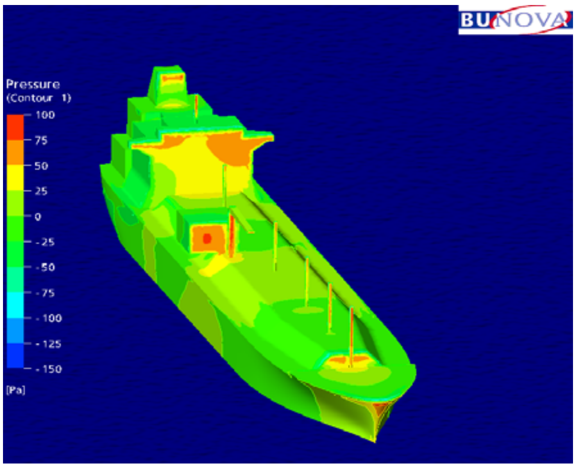
- Trial program and procedures: ship condition, site, weather, heading, # runs,
- Measurements: speed, power, wind, waves,
- Analysis procedures: resistance/power, draft conversion,
- Correction methods: wind, waves, shallow water, temp, density.

Accuracy and Certification Power Measurements:



Some discrepancies from the case study (20 vessels):

- Wind and wave data,
- Conversion of ballast trial results to laden condition by means of model test data,
- Use of out dated correction methods,
- Large variation in correction method results.



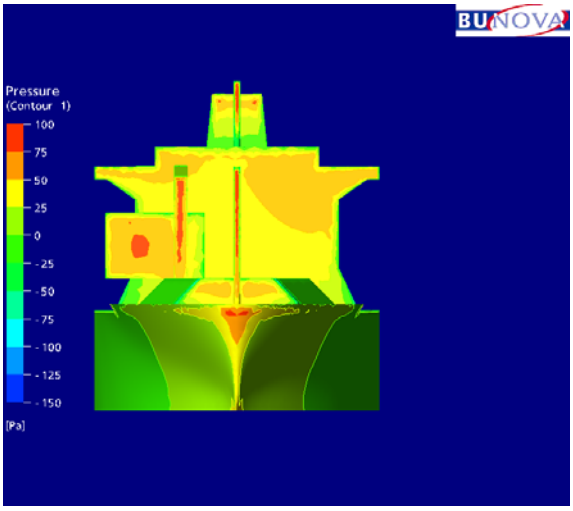


Figure 1.1- 138000m^3 LNGC, CFX –wind load computation, pressures.

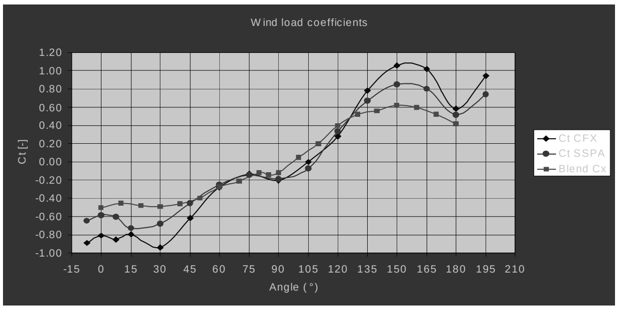


Figure 1.2- Wind loads, comparison Drag Coefficient, C_X.

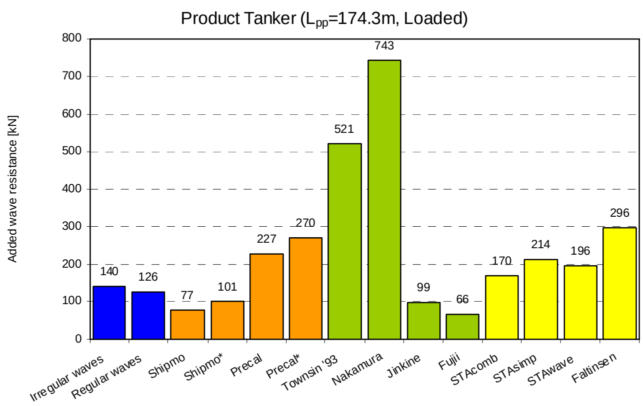


Figure 1.3- Correction methods for waves.

<u>For ITTC discussion.</u>

- How are model extrapolations affected by ‘optimistic’ trial results?
- Can ITTC provide standard for reliable model tests data to be used for draft conversion?

- How can we improve added resistance model tests and computational models for sea trial wave conditions?

1.2 By Dr. Naoji Toki, Mitsubishi Heavy Industries Ltd., Japan, on Monitoring of Service Performance of a ROPAX Ferry

Introduction. When our Shimonoseki Shipyard completed a pair of ROPAX Ferries, we set a monitoring P/C and the interface equipment on one of the pair. The pair of ferries, propelled by two medium-speed diesel engines and CPPs, are operating between Kita-Kyushu and Osaka through Seto-Inland-Sea, leaving one port in the evening and arriving another in next the morning (one way each, daily service). The route is shown below.

By now, service records for almost two years were piled up and, by analysing the data, it seems that very interesting results are coming out.

In this discussion, the specifications and the analysed results of this monitoring are summarised.

Specifications of the Monitoring. The monitoring P/C and the interface equipment were set in the steering bridge of the ship. The monitored items are as follows:

1. Day and time,
2. Ship's position (longitude and latitude),
3. Ship speed relative to ground,
4. Relative wind velocity and wind direction,
5. Draughts at fore and aft,
6. Rudder Angles,
7. Engine loadings and revolutions (Port and starboard engines),
8. CPP pitch angles (Port and starboard propellers),
9. Water Depth.

The monitored items are being recorded on the hard disc of the PC every second. However, the items (7) and (8) are refreshed only once about every thirty seconds, because they are being transferred from the "Engine Data Logger". The other items are taken from the measuring equipments on the bridge, and the change in seconds could be identified.

Unfortunately, this ship is not equipped with torsion meters and sensor of ship speed relative to water. Engine output (BHP) was estimated from the output of loading indicator and engine revolution by a formula prepared by the analysis of the results of official sea trial, during which the values of shaft horsepower were measured by temporarily set torsion meters.

Ship speed relative to water is obtained by the analysis of engine output and propeller revolution, as explained later. Current speed was calculated by subtracting the monitored value of ship speed relative to ground.

Summary of Analysis. Daily Records: The ferry is engaged in voyage of about twelve hours every day. The averaged value in every 20 seconds were transferred into an Excel file, analyzed and checked. It means around 2,200 data/monitored item, for one voyage. Examples of time-histories of ship speed, total power and rudder angle during a voyage are shown in the following figure.

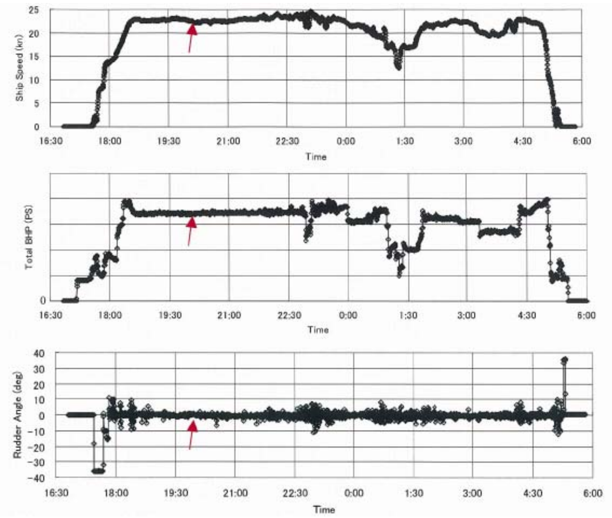


Figure 1.4- Examples of time-histories of during a voyage.

Sampling of Service Performance Data: After the certain amount of daily records were checked, one place was selected where:

a) Water is deep enough (about 47m),
b) Usually, the ship passes through the place with almost constant settings.

The place is marked by a small red circle on the route map, and the timings passing through there are marked in Fig. 1.4 by three red arrows.

From the monitored records of daily operations when the ship was passing through there, mean values of the measured items (3), (4), (7) and (8), mean value and standard deviation of the measured item (6) are calculated.

For the measured item (5), fore and aft draughts, the measured values of static pressure are converted to the values of draught. Therefore, the records obtained while the ship is running at considerable speed are considered to contain the effect of dynamic pressure. Then, the average values at very low speed were calculated and used as the draughts of the voyage.

Full-scale propeller open-water characteristics were estimated for various values of propeller pitch angle and the fitted formula were obtained based on them. The propeller open-water characteristics corresponding to the mean of mean values of propeller pitch angle were calculated by use of the formula, and used for the analysis.

Analysis of Service Performance Data: According to our procedure of sea trial data analysis, the following calculation procedure was formulated to analyze the obtained average values of BHP and N_p (brake horse power and propeller revolution).

J is derived for the obtained K_Q from propeller open-water characteristics and K_T is derived for the obtained J from propeller open-water characteristics. It is our practice to use $\nabla^{2/3}$ to obtain non-dimensional coefficients of total resistance and residual resistance.

BHP
N_P

$$\Rightarrow \mathrm{DHP} = \left(\mathrm{BHP} - S_{tern}T_{ube}L_{oss} \times \frac{\mathrm{BHP}_{MCR} \times N_P}{N_{P,MCR}}\right) \times \frac{\mathrm{SHP}}{\mathrm{BHP}} \times \frac{1}{\mathrm{No.of\ Prop.}}$$

$$K_Q = \frac{24668 \times \mathrm{DHP} \times \eta_r}{N_P{}^3 \times D_P{}^5} \Rightarrow J$$

$$V_{S,W}\ (\text{relative to water}) = \frac{J \times N_P \times D_P}{60 \times 0.51444 \times (1 - w_S)}$$

$$R\,(\mathrm{ton}) = \frac{0.029 \times K_T \times N_P{}^2 \times D_P{}^4 \times (1-t) \times \mathrm{No.of\ Prop.}}{1000}$$

$$C_T = \frac{72.303 \times R(\mathrm{ton})}{V_{S,W}(\mathrm{kn})^2 \times \nabla^{2/3}},$$

$$\Delta C_r = C_T - \frac{\zeta}{\log(Rn)^{2.58}} \times \frac{S_a}{\nabla^{2/3}} - C_r$$

where,
D_p: Diameter of the propeller,
R: Resistance of the ship,
w_s and w_m: Wake fraction factors for ship and model,
e_i: Wake correction factor (obtained as a result of sea trial),
t, w_m, η_r: Self-propulsion factors (obtained by model test),
C_T: Total resistance coefficient of ship,
S_a: Wetted surface area,
ζ: Model-ship correlation factor for friction correction for ship (obtained as a result of sea trial), where a modified Prandtl-Schlichiting line is used,

C_r: Residual resistance coefficient (obtained by model test).

Thus, one set of values of ΔC_r and are obtained from the monitored results for one day. From the value of $V_{S,W}$ and the mean value of monitored ship speed relative to ground ($V_{S,G}$), current velocity (V_C) was calculated by the following formula.

V_C (current velocity) = $V_{S,W} - V_{S,G}$

Analyzed Results: Trend graph of V_C is shown in Fig. 1.5. Current velocity (V_C) for both of East and West-ward voyages scatter within ±1.0 kn and it seems to be quite reasonable. It means that the relations among the measured propeller revolution, CPP pitch angles and the estimated engine power, propeller open-water characteristics have no major contradictions.

Relations between analyzed ship speed and measured BHP is shown in Fig. 1.6, and trend graph of $\Delta C_{r,0}$ (ΔC_r as measured) is shown in Fig. 1.7. Considerable scatter of BHP over $V_{S,W}$ corresponds to scatter of $\Delta C_{r,0}$. Scatter of ΔC_r: 0.005 corresponds to more than 25% of the estimated total resistance coefficient. Because ROPAX ferries have big super-structures, air resistance is considered a main cause of the scatter, and calculated by the following formula:

$$\Delta R_{air} = \frac{\rho_{air}}{2} \times A \times V_{RelativeWind}^{2} \times C_X \times f(\theta_{RelativeWind})$$

where,
C_X: Air resistance coefficient for head wind,
A: Area of the ship above water projected to the transverse section of the ship,
$V_{Rel.Wind}$ and $\theta_{Rel.Wind}$: The average values of relative wind velocity and direction,
f(θ): Function showing the effect of wind direction on wind resistance coefficient.

ΔR_{air} was subtracted from R in the above formulae, and the values of $\Delta C_{r,corrected}$ (ΔC_r corrected to no air) were obtained. The trend graph of ΔC_r, corrected is shown in Fig. 4. The scatter of ΔC_r, corrected reduced very much in comparison with that of $\Delta C_{r,0}$ and $\Delta C_{r,\ corrected}$ remains very close to 0.

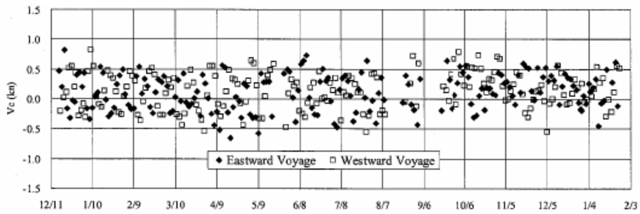


Figure 1.5- Trend of Current Velocity (V_C).

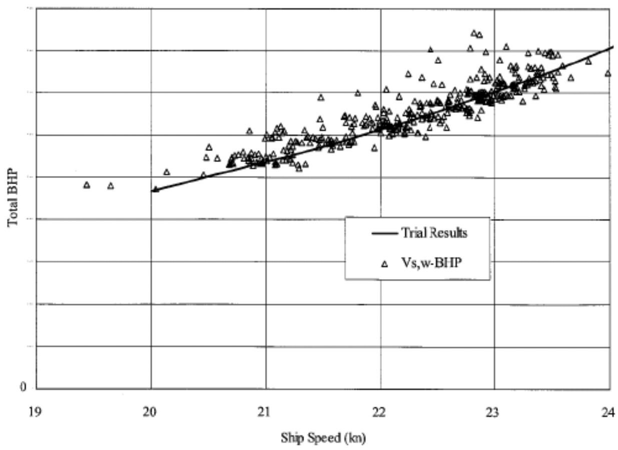


Figure 1.6- Relationship between Ship Speed and BHP.

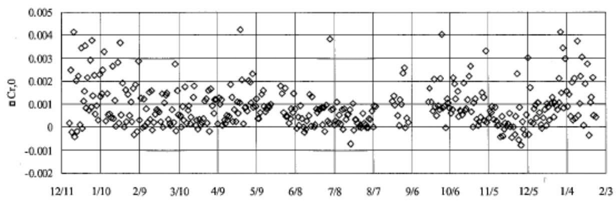


Figure 1.7- Trend of $\Delta C_{r,0}$ (as measured).

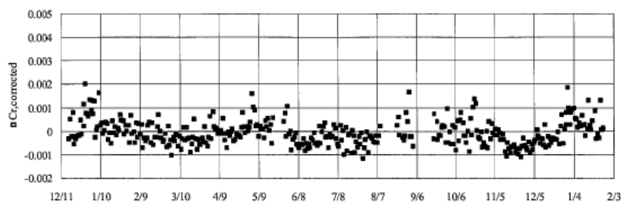


Figure 1.8- Trend of ΔC_r (corrected to no air condition).

Relation between ship speed and BHP corrected to no wind condition is shown in Fig.

1.9. It is noticed that scatter of BHP over Vs reduced very much when compared with Fig. 1.6.

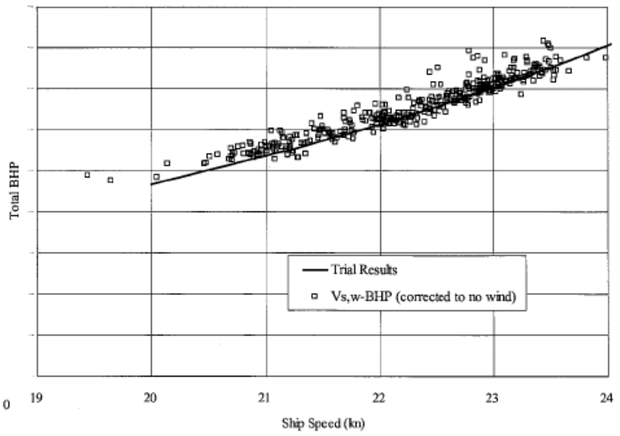


Figure 1.9- Relationship between Ship Speed and BHP (corrected to no wind condition).

Difference of BHP from the line of trial results (ΔBHP) were calculated and plotted over the value of mean draught in Fig. 1.10. It is understood that the effect of operation condition is evident, which is properly accounted for in this analysis.

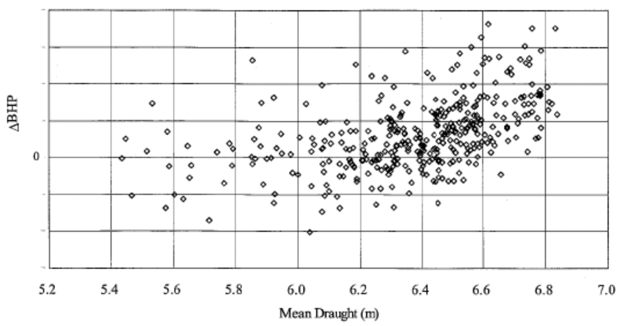


Figure 1.10- Relationship between ΔBHP (difference from trial results) and mean draught.

Concluding Remarks. For one of the ROPAX ferries constructed by MHI, monitoring records of service performance were accumulated for almost two years. From the analyzed results of the data while passing through one area, it seems that we can conclude as follows:

1. Owing to the good maintenance by the owner, the ROPAX ferry is operating almost in the same performance as that when she was newly constructed, which was predicted by model tests and confirmed during the official sea trials.
2. Resistance (or power) increase on the ROPAX ferry was mainly due to wind. The effect of waves on resistance increase is almost negligible. It is simply because ROPAX ferries have a big superstructure and waves on this route are generally calm.
3. Because the operation condition (namely draught) of ROPAX ferry varies every day, not only the effects of ship speed and environmental conditions on her performance but also the effect of operation condition should be considered. However, it is very difficult to evaluate the whole effects by just plotting BHP over Vs like Fig. 1.6 and Fig. 1.9.
4. The application of our trial analysis procedure to actual performance analysis could give a better view. It is because the analysis procedure is based on reasonable expressions of hydrodynamic characteristics of ship's performance.
5. It is somewhat surprising that such good results of performance analysis was obtained from actual operation monitoring, even without torsion meters. One reason can be the main engine characteristics were very stable, owing to the good maintenance by the owner, during this term of monitoring.

We also started the monitoring of another ROPAX ferry, which is operating in the Pacific Ocean along the coast of Japan (where the effect of waves cannot be neglected) and equipped with torsion meters and electro magnetic velocity meter (velocity meter relative to water). We hope even more interesting results would come out in the near future.

1.3 By Rear Adm. Pascual O'Dogherty, former Superintendent of CEHIPAR, Spain, on a note on model-ship correlation for single-screw vessels, based on the collation of ship trials data

Abstract. This discussion presents a simplified method for model-ship correlation of single-screw vessels, based on the use of C_A, incremental resistance coefficient for Ship-Model correlation, to be applied in connection with the ITTC-57 friction line. The value of C_A has been obtained by the collation of model data and ship trials information.

Nomenclature.

B:	Moulded breadth, m.
BHP = P_B:	Brake Horse Power, metric HP.
BSRA:	British Ship Research Association.
B/T:	Breadth/Draught ratio.
C_A:	Incremental resistance coefficient for Ship-Model correlation.
C_{AST}:	C_A deducted from Ship Trials results.
C_B:	Block coefficient.
C_B.B/L:	Coefficient of fineness.
CEHIPAR:	Canal de Experiencias Hidrodinámicas de El Pardo.
C_{FS}, C_{FM}:	Frictional resistance coefficients (ship and model, respectively), according to the ITTC-57 friction line.
C_P:	Froude Power correction factor.
C_R:	Residuary resistance coefficient (ship and model): [$C_R = C_{TM} - C_{FM}$].
C_{TM}:	Total resistance coefficient for the model.
C_{TS}:	Total resistance coefficient for the ship: [$C_{TS} = C_{FS} + C_R + C_A$].
C_{TSM}:	Ship total resistance coefficient (model tests).
C_{TSS}:	Ship total resistance coefficient (ship trials).
D:	Propeller diameter, m.
DHP = P_D:	Delivered Horse Power, metric HP.
EHP = P_E:	Effective Horse Power, metric HP.
ISP:	International Shipbuilding Progress.
ISSHES:	International Symposium on Ship Hydrodynamics and Energy Saving.
J_{QM}:	Advance coefficient (model) [$J_{QM} = 30.8668 \times V(1-W_{QM})/(D \times N)$].
J_{QS}:	Advance coefficient (ship) [$J_{QS} = 30.8668 \times V(1-W_{QS})/(D \times N)$].
K_{QM}:	Propeller torque coefficient (model).
K_{QS}:	Propeller torque coefficient (ship).
K_2:	RPM correlation factor.
LBP, L:	Length between perpendiculars, m.
N:	Propeller RPM (tests).
Q:	Propeller torque, m.Kp.
T_M, T:	Mean moulded draught, m.
V:	Ship speed, knots.
W:	Taylor wake fraction.
W_{QM}:	Wake fraction (torque identity, model).
W_{QS}:	Wake fraction (torque identity, ship).
W_{QST}:	Wake fraction (torque identity, from tank predictions).
ΔW_Q:	Wake scale effect (torque identity): [$\Delta W_Q = W_{QM} - W_{QS}$].
η_D = QPC:	Propulsive efficiency: [$\eta_D = P_E/P_D$].
η_S:	Shafting efficiency: [$\eta_S = P_D/P_B$].
λ:	Scale ratio.

Introduction. The author was appointed to work at El Pardo Model Basin in 1964, when all the tests at El Pardo and most Model Basins were made according to the Froude-Froude system whereas the ITTC-57 friction line was having a limited use in model testing. At the same time Shipbuiding was having an extraordinary boom, involving the construction of very large Tankers, Bulk-carriers and LNGs. For normal medium-sized ships, with the Froude-Froude system, ship trials predictions required to use C_P values, such as C_P = 1.15. Nevertheless, with the increase in ship lengths the needed values of C_P had to change dramatically, reaching C_P values that were lower than 0.85 in the case of very large tankers. As a matter of fact, CEHIPAR issued regularly speed certificates for new ships built in the Spanish Yards, after analysing the ship trials results, in connection with the results of model tests performed at CEHIPAR. This information permitted to find the correct C_P needed for each vessel and the "equivalent C_A" in case of using the ITTC-57 friction line. As from 1964, the author started to calculate C_A values for all the single-screw ship types, work that was intensified from 1970, when he decided to implement the ITTC-57 friction line for model tests.

Derivation of C_A. As stated before, the derivation of an empirical formula for C_A involved the continuous analysis of ship trials results, in order to calculate the C_A that should have been needed in calculating the Tank predictions so that the ship results (P_B, V, RPM) for a given condition would coincide with the tank predictions. This attempt poses a very difficult task if we consider the many aspects that influence the Ship trials results, such as the following:

- The different weather conditions, sea and wind,
- The difference that may exist between the ship draughts tested in the tank and the draught in the sea trials,
- The existence of currents and tidal streams, during the Ship trials (O'Dogherty, 1975c),
- The influence of the approach distance to the measured mile (O'Dogherty, 1975b and 1975c), so that an insufficient approach distance would reduce the ship speed, when entering the measured mile, as she shall be in acceleration period after turning, failing to reach the full speed that corresponds to the engine power,
- The fouling of the hull and propeller, if the sea trials are not performed shortly after docking,
- The possible difference of the ship propeller (may be pitch-adjusted from the model propeller) from the propeller tested in the tank, what may be more significant in the case of the tests having been carried out with a stock propeller,
- The speed reduction and the modification of RPM in the case of testing in shallow waters (Acevedo, 1966)
- The existence of propeller cavitation, not observed in model tests,
- Possible differences in the evaluation of the shafting efficiency, η_S.

For this analysis, C_A has been calculated in most cases for ship trials performed in favourable weather conditions, not exceeding Beaufort 2, in deep waters, with clean hull and ship results certified by the Ministry of Transport, the draughts corresponding to a condition tested in the tank.

It is assumed with Prof. Aertssen (Aertssen) that the value of η_D, as a function of V, is the same for ship and model, so that:

$$P_B \text{ (ship trials)} / P_B \text{ (model tests)} = P_E \text{ (ship trials)} / P_E \text{ (model tests)} = C_{TSS} / C_{TSM} \quad (1.1)$$

$$C_{TSS} = C_{TSM} \times P_B\text{trials} / P_B\text{tests} \quad (1.2)$$

$$\text{Corrected } C_A = C_{AST} = C_A\text{tests} + C_{TSS} - C_{TSM} \quad (1.3)$$

Deduction of K_2. The value of K_2 to be used in the calculation of the trials predictions is intimately linked to the value of the wake scale effect, $\Delta W_Q = W_{QM} - W_{QS}$.

If a good estimate of ΔW_Q is not known, K_2 can be estimated by the formulae:

$$K_2 = 1 + 0.004\lambda^{1/2} \text{ (Full load)} \quad (1.4)$$

$$K_2 = 1 + 0.006\lambda^{1/2} \text{ (Ballast)} \quad (1.5)$$

When ΔW_Q is known, K_2 my be calculated by the formula:

$$K_2 = 1 + \Delta W_Q / 3 \quad (1.6)$$

Otherwise it may be obtained by trial and error, until a value of K_2 is found to satisfy the desired value of ΔW_Q.

An example is shown of the calculation of K_2 for a large tanker, whose main dimensions are the following:

- LBP = 315 m,
- B = 55 m,
- T_{Load} = 20 m,
- C_B = 0.8355,
- $T_{Ballast}$ = 11 m.

Sea trials in ballast, V = 17 knots, P_B = 36387 HP, N = 94.3 rpm, Beaufort 2 W_{QS} (sea trials) = 0.45.

From the tank tests at the same condition:

- V = 17.1 knots,
- P_B = 36008 HP,
- N = 89.15 rpm,
- W_{QM} = 0.6,
- ΔW_Q = 0.6 - 0.45 = 0.15.

For this condition several values of K_2 were assumed. The results are indicated in the following table:

K_2	W_{QST}	$\Delta W_Q = 0.6 - W_{QST}$
1.03	0.518	0.082
1.04	0.487	0.113
1.05	0.458	0.142
1.055	0.443	0.157

The value of K_2 = 1.052 was interpolated to correspond to ΔW_Q = 0.15.

In fact, a value of K_2 = 1.04 was used in the tests, while Eq. 1.5 gave the value K_2 = 1.041, using the scale factor λ = 46. Equation 1.6 gave K_2 = 1.05.

Proposed Formula for C_A. When CEHIPAR created a database some thirty years ago (Carlier and O'Dogherty, 1983), it was found that the main parameters to influence ship resistance were the following:

1. Ship length,
2. Ship fineness, defined by a "coefficient of fineness" = $C_B \times B/L$,
3. Beam/Draught ratio.

It was considered a logical decision to relate the C_A value for a ship to the values of the three parameters already defined. The study of many values of C_A calculated at CEHIPAR, by means of regression analysis, permitted to establish the formula:

$$C_A \times 10^5 = 73 + 320 C_B \times B/L - 15 L^{0.45} + 46(B/T)^{0.41} \qquad (1.7)$$

The C_A values given by Eq. 1.7 were used systematically at CEHIPAR in the calculation of power predictions for single-screw vessels, providing in general a good guidance in the evaluation of the ship trials results.

Conclusions. Equation 1.7 has been used at CEHIPAR for all types of single-screw vessels, with satisfactory agreement to full size powering values in normal trials conditions.

The parameter B/T permits that Eq. 1.7 for C_A could be applied for all loading conditions. It is considered that a closer agreement with the full size results could be attained is a similar analysis is made with a large number of vessels, endeavouring to obtain particular formulae for C_A, to apply to different ship types, such as very large tankers, bulk-carriers, warships, fishing boats, medium-sized cargo ships, Ro-Ros, etc.

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