ITTC Circular Letter

May, 2016

Load variation tests

The speed/power sea trials procedures, ITTC Recommended Procedures 7.5-04-01-01.1 and -01.2, and ISO15016:2015 require that load variation tests are performed in connection with propulsion tests (described in ITTC Recommended Procedure 7.5-02-03-01.1, chapter 3.4.1.1 – 3.4.1.3) as a minimum for the EEDI condition, but also for the ballast condition when EEDI condition cannot be achieved during the sea trials. In order to be able to evaluate the sea trial measurements the load variation coefficients shall be reported in the test report in connection with the speed power trial prediction for the full scale ship. (Recommended Procedure: 7.5 – 02 -03 -01.4). See also the appended excerpt of ISO 15016:2015.

The ITTC Propulsion Committee has been given the task to update the relevant ITTC Recommended Procedures to account for this. A draft of this extension to ITTC Recommended Procedures 7.5-02-03-01.1 and 7.5-02-03-01.4, giving a description how to calculate the load variation coefficients, is shown in the appended document “Load variation test – draft procedure”.

ITTC members are advised already now to perform the specified load variation tests and to report the coefficients in their test reports because since June 2015 the use of the load variation coefficients for the evaluation of sea trial measurements for the verification of the EEDI of IMO is obligatory.

signed

ITTC Executive Committee

Load variation test –draft procedure

A load variation test is carried out at the trial draught and at minimum one speed close to the predicted EEDI speed (75%MCR). This speed shall be one of the speeds tested in the normal self-propulsion test. The load variation test includes at least 4 self-propulsion test runs, each one at a different rate of revolution while keeping the speed constant. The rate of revolutions are to be selected such that

$$\frac{\Delta R}{R_0} \approx [-0.1, 0{,}0.1{,}0.2] \tag{D-9}$$

where

$$\Delta R = (F_\mathrm{D} - F_\mathrm{X})\lambda^3 \frac{\rho_\mathrm{S}}{\rho_\mathrm{M}} \tag{D-10}$$

R_0: full scale resistance without overload at the selected speed at full scale, same as R_{TS} derived from resistance test

F_X: external tow force, measured during load variation test

F_D: skin friction correction force, same as in the normal self-propulsion tests

λ: scale factor

ρ_S, ρ_M: water density at full scale and model test

The "added resistance" in the load variation test has to be accounted for in the post processing. The measured data is processed according to ITTC Recommended Procedure 7.5–02–03–01.4 (1978 ITTC Performance Prediction Method), from section 2.4.3 and onwards, prepared for the standard self-propulsion test at tow force F_D with one modification. that C_{TS} is replaced by C_{TSAdd} with

$$C_\mathrm{TSAdd} = C_\mathrm{TS} + \frac{\Delta R}{1/2\, \rho_\mathrm{S} {V_\mathrm{S}}^2 S_\mathrm{S}} \tag{D-11}$$

where

V_S: full scale ship speed

S_S: full scale wetted surface, same values as used in normal self-propulsion test

Dependency of propulsion efficiency with resistance increase

The fraction between the propulsion efficiency considering the load variation effect η_{DM} and that in ideal condition η_D is plotted against the fraction between the resistance increase ΔR and resistance in ideal condition R_0. Figure D-1 shows an example. The variable ξ_P is the slope of the linear curve going through {0,1} and fitted to the data points with least square method.

Dependency of shaft rate with power increase

Similarly, the effect on shaft rate $\Delta n/n$ (the fraction between the deviation of shaft rate due to load variation effect Δn and the shaft rate in ideal condition n) is plotted against $\Delta P/P_{D0}$ (the fraction between power increase ΔP and the power in ideal condition P_D). The variable ξ_n is the slope of the linear curve going through {0,0} and fitted to the data points with least square method. Figure D-2 gives an example.

Dependency of shaft rate with speed change

The dependency of shaft rate with speed is derived through the following steps:

The shaft rate n in ideal condition is plotted against the resistance $R_0+\Delta R$ ($\Delta R=0$) for a number of speeds in the same graph (red * in Figure D-3)

The shaft rate n considering the load variation effect is plotted against the resistance $R_0+\Delta R$ ($\Delta R\neq 0$) for the speed closest to the predicted EEDI (black points in Figure D-3).

In addition, the linear curve going through $\{R0 , n\}$ and fitted to the data points $\{R_0+\Delta R, n\}$ is obtained with least square method.

Lines going through the point $\{R0 , n\}$ for each speed and parallel to the linear curve obtained above are plotted. (red lines in Figure D-3).

A vertical line going through the resistance in ideal condition for the speed closest to the predicted EEDI speed is plotted in the graph (green line in Figure D-3)

From the intersections of the green line and the red lines (green square □), the shaft rate for the corresponding speed of the each red line can be obtained.

For each of the intersection points, compute $\Delta V/V$ relative to the speeds which is closest to the predicted EEDI speed.

For each of the intersection points, compute $\Delta n/n$ relative to the n-values which is closest to the predicted EEDI speed.

These points in a $\Delta n/n$ over $\Delta V/V$ graph (Figure D-4) are plotted. This gives the rpm dependency of speed.

The slope of the $\Delta n/n$ - $\Delta V/V$ curve fitted with least square method is ξv (Figure D-4).

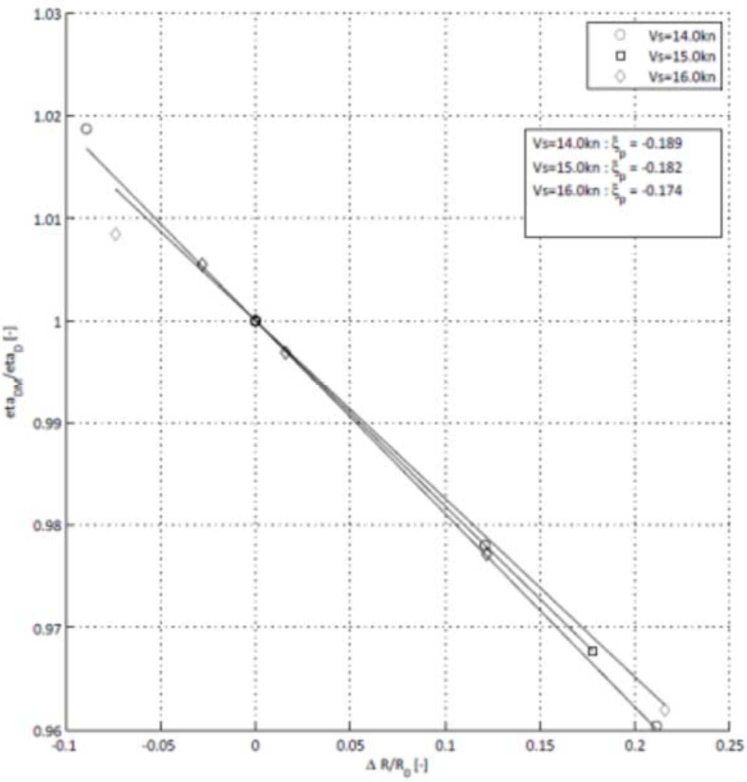

Figure D-1 Relation between propeller efficiency and resistance increase

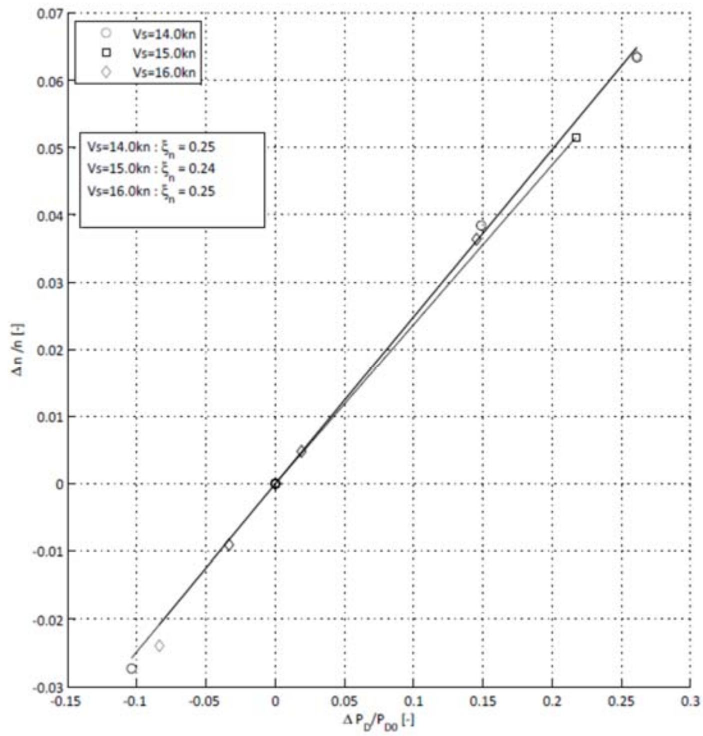

Figure D-2 Relation between propeller rate and power increase

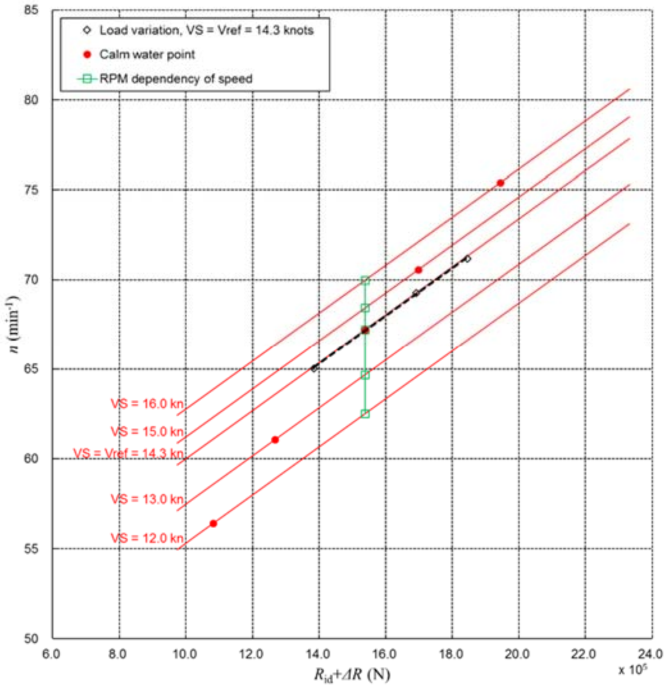

Figure D-3 Relation between propeller rate and speed change

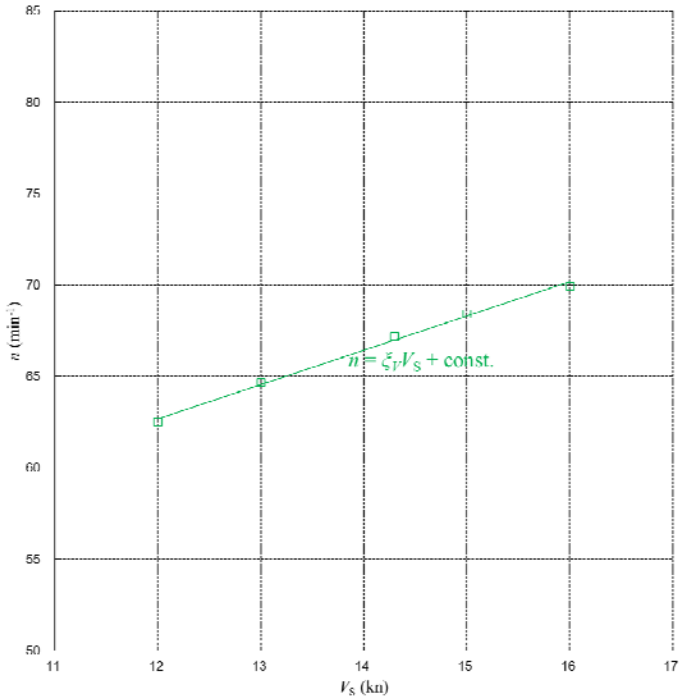

Figure D-4 Relation between propeller rate and speed change, second step

Figure 5 — flow chart of analysis

11.2.1 Resistance data derived from the acquired data

The resistance values of each run shall be corrected for environmental influences by estimating the resistance increase ΔR as

$$\Delta R = R_{AA} + R_{AW} + R_{AS} \qquad (7)$$

where:

ΔR : is the total resistance increase in newtons,

R_{AA} : is the resistance increase due to relative wind in newtons (see Annex C),

R_{AW} : is the resistance increase due to waves in newtons (see Annex D),

R_{AS} : is the resistance increase due to deviation of water temperature and water density in newtons (see Annex E).

11.2.2 Evaluation of the acquired data

The evaluation of the acquired data consists of the calculation of the resistance value associated with the measured power value separately for every single run of the speed trials.

The reason that the associated resistance/power shall be calculated for each run is that a careful evaluation shall consider the effects of varying hydrodynamic coefficients with varying propeller loads. The recommended correction methods (except for the ones used for current effect, for shallow water effect and for displacement) are applicable to resistance values.

11.2.3 Evaluation based on Direct Power Method

To derive the speed/power performance of the ship from the measured speed over the ground V_G, power P_{ms} and propeller shaft speed n_{ms}, the 'direct power' method shall be used.

The analysis is based on the delivered power. The relationship between delivered power in the trial condition P_{Dms} and measured power is described in the following formula:

$$P_{Dms} = P_{Sms} \cdot \eta_S \qquad (8)$$

where:

P_{Dms} : is the delivered power in the trial condition in watts,

P_{Sms} : is the measured shaft power in watts,

η_S : is the shaft efficiency,

or:

$$P_{Dms} = P_{Bms} \cdot \eta_M \qquad (9)$$

where:

P_{Dms} : is the delivered power in the trial condition in watts,

P_{Bms} : is the measured brake power in watts,

η_{M} : is the transmission efficiency.

In this method, the delivered power P_{Dms} is directly corrected with the power increase ΔP due to resistance increase ΔR in the trial condition.

$$P_{\mathrm{Did}} = P_{\mathrm{Dms}} - \Delta P \tag{10}$$

where:

P_{Did} : is the delivered power in the ideal condition in watts,

P_{Dms} : is the delivered power in the trial condition in watts,

ΔP : is the required correction for power in watts.

The required correction for power ΔP is calculated by the following formula:

$$\Delta P = \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} + P_{\mathrm{Dms}}\left(1 - \frac{\eta_{\mathrm{Dms}}}{\eta_{\mathrm{Did}}}\right) \tag{11}$$

where:

ΔP : is the required correction for power in watts,

ΔR : is the total resistance increase in newtons,

V_{S} : is the ship's speed through the water in metres per second,

P_{Dms} : is the delivered power in the trial condition in watts,

η_{Dms} : is the propulsive efficiency coefficient in the trial condition,

η_{Did} : is the propulsive efficiency coefficient in the ideal condition.

The propulsive efficiency coefficient in the ideal condition η_{Did} is obtained from standard towing tank test and interpolated to the speed V_{S}.

The effect of resistance increase on the propeller loading and thus on the propulsive efficiency coefficient η_{Dms} is derived considering the load variation effect.

The propulsive efficiency is assumed to vary linearly with the added resistance according to:

$$\frac{\eta_{\mathrm{Dms}}}{\eta_{\mathrm{Did}}} = \xi_P \frac{\Delta R}{R_{\mathrm{id}}} + 1 \tag{12}$$

where:

η_{Dms} : is the propulsive efficiency coefficient in the trial condition,

η_{Did} : is the propulsive efficiency coefficient in the ideal condition,

ξ_P : is derived considering the load variation effect as described in Annex J,

ΔR : is the total resistance increase in newtons,

R_{id} : is the resistance in the ideal condition in newtons.

This leads to the expression for the corrected delivered power:

$$P_{\mathrm{Did}} = P_{\mathrm{Dms}} - \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} \left(1 - \frac{P_{\mathrm{Dms}}}{P_{\mathrm{Did}}} \xi_P \right) \tag{13}$$

Then, the following quadratic equation about P_{Did} is obtained by transforming equation (13):

$$P_{\mathrm{Did}}^2 - \left(P_{\mathrm{Dms}} - \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} \right) P_{\mathrm{Did}} - P_{\mathrm{Dms}} \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} \xi_P = 0 \tag{14}$$

Finally, P_{Did} is obtained as follows under the condition ($P_{\mathrm{Dms}} - \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} > 0$).

$$P_{\mathrm{Did}} = \frac{1}{2} \left(P_{\mathrm{Dms}} - \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} + \sqrt{ \left(P_{\mathrm{Dms}} - \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} \right)^2 + 4 P_{\mathrm{Dms}} \frac{\Delta R V_{\mathrm{S}}}{\eta_{\mathrm{Did}}} \xi_P } \right) \tag{15}$$

where:

P_{Did} : is the delivered power in the ideal condition in watts,

P_{Dms} : is the delivered power in the trial condition in watts,

ΔR : is the total resistance increase in newtons,

V_{S} : is the ship's speed through the water in metres per second,

η_{Did} : is the propulsive efficiency coefficient in the ideal condition,

ξ_P : is derived considering the load variation effect as described in Annex J.

The correction of the propeller shaft speed is also carried out considering the load variation effect.

With the P_{Did} found as described above, the correction on propeller shaft speed is:

$$\frac{\Delta n}{n_{\mathrm{id}}} = \xi_n \frac{P_{\mathrm{Dms}} - P_{\mathrm{Did}}}{P_{\mathrm{Did}}} + \xi_V \frac{\Delta V}{V_{\mathrm{S}}} \tag{16}$$

and:

$$\Delta n = n_{\mathrm{ms}} - n_{\mathrm{id}} \tag{17}$$

From this follows that the corrected propeller shaft speed n_{id} is

$$n_{id} = \frac{n_{ms}}{\xi_n \frac{P_{Dms} - P_{Did}}{P_{Did}} + \xi_V \frac{\Delta V}{V_S} + 1} \tag{18}$$

where:

n_{ms} : is the measured propeller shaft speed in revolutions per second,

n_{id} : is the corrected propeller shaft speed in revolutions per second,

P_{Did} : is the delivered power in the ideal condition in watts,

P_{Dms} : is the delivered power in the trial condition in watts,

ξ_n, ξ_V : are derived considering the load variation effect as described in Annex J,

V_S : is the ship's speed through the water in metres per second,

ΔV : is the decrease of ship's speed due to shallow water in metres per second, determined in Annex G.

The analysis in Annex K, which is included in this document, is useful to deepen the technological knowledge, since this calculation is based on the full-scale wake fraction.

11.2.4 Correction of the measured ship's speed due to the effect of current

The current effect is corrected by subtracting the current speed V_C from the measured ship's speed over the ground V_C at each run as follows:

$$V_S = V_G - V_C \tag{19}$$

where:

V_S : is the ship's speed through the water in knots,

V_G : is the measured ship's speed over ground in knots,

V_C : is the current speed in knots.

The current correction can be applied by two (2) different methods:

y) <u>'Iterative' method</u>

Based on the assumption that the current speed varies with a semi-diurnal period, a current curve as a function of time will be created. In the same process a regression curve representing the relationship between the ship's speed through the water (formula 19) and corrected power (clause 11.2.3) is determined. So both current curve and regression curve are created in one process. The regression curve has no relation with the speed/power curve from the tank tests.