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How to divide the global resistance change into the components related to the pushing propeller and the pulling propeller of the double-ended ship

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ABSTRACT

The division of the global resistance change ΔR_{R+D} due to the simultaneous action of the pushing (SR) and pulling(SD) screw propellers into the components ΔR_R and ΔR_D can be done by taking into account two different procedures and different hypothetical assumptions given in the form of the division coefficients $(A_j)_R$ and $(A_j)_D$, the same in each procedure.

In the procedure no1: $\Delta R_R = \Delta R_{R+D}(A_j)$ and $\Delta R_R = \Delta R_{R+D}(A_j)_{Dj}$

In the procedure no 2: $\Delta R_R = T_R - (R_0 - F_D)\,(A_j)_R$ and $\Delta R_D = T_D - (R_0 - F_D)\,(A_j)_D$

Two necessary conditions were formulated to be fulfilled when selection of the coefficients $(A_j)_R$ and $(A_j)_D$ is done. The results of the analysis are univocal. Among the possible division coefficients only one pair of them fulfills the formulated conditions. This pair is:

$$(A_1)_R = \frac{T_R}{T_{R+D}} \quad \textit{and} \quad (A_1)_D = \frac{T_D}{T_{R+D}}$$

Keywords: self propulsion tests, double-ended ships, resistance change due to propeller action.

INTRODUCTION

In model self propulsion tests, among other problems, the model resistance changes due to propeller action can be investigated. In the case of a ship with the pushing screw propeller (SR) the procedure of determination of the ship hull resistance change is well known from the ITTC Recommendation:

$$\Delta R = T - (R_0 - F_D) \tag{1}$$

where:
ΔR - ship hull resistance change
R_0 - ship hull resistance when towed (from resistance test)
T - screw propeller thrust (measured)
F_D - additional towing force (calculated)

In special cases, e.g. double ended ferry fitted with pushing, SR, and pulling, SD, screw propellers being in simultaneous action the determination of the global resistance change can be performed according to the known ITTC Recommendations:

$$\Delta R_{R+D} = T_R + T_D - (R_0 - F_D) = T_{R+D} - (R_0 - F_D) \tag{2}$$

where:
T_R, T_D - thrust of SR and SD screw propellers (measured values)
R_0 - ship hull resistance when towed (from resistance test)
F_D - additional towing force (calculated)
ΔR_{R+D} - global ship resistance change due to simultaneous action of SR and SD propellers.

The mentioned ITTC Recommendations do not give any instruction related to the necessary procedure of dividing the global resistance increase ΔR_{R+D} into the components ΔR_R and ΔR_D due to the both screw propellers SR and SD. Additional hypothetical assumptions are to be proposed to form this dividing procedure.

In this paper an analysis of the possible hypothetical assumptions is given from the point of view of the necessary conditions formulated by the author.

POSSIBLE PROCEDURES AND HYPOTHESES

The division of the global resistance change ΔR_{R+D} due to the simultaneous action of the pushing screw propeller SR and the pulling screw propeller SD into the components ΔR_R and ΔR_D can be done by taking into account two different procedures and different hypothetical assumptions, the same in each procedure.

Two possible procedures are evident from the formal twofold notation of the division way.

The first procedure (i = 1) makes direct use of the components ΔR_R and ΔR_D which are combined with the division coefficients $(A_j)_R$ and $(A_j)_D$ in the form:

$$\Delta R_R = \Delta R_{R+D}(A_j)_R$$
$$\Delta R_D = \Delta R_{R+D}(A_j)_D \qquad (3)$$

The second procedure (i = 2) refers to the notation of global resistance change in the form (2):

$$\Delta R_{R+D} = T_{R+D} - (R_0 - F_D)$$

and makes use of the similar notation related to the components ΔR_R and ΔR_D:

$$\Delta R_R = T_R - (R_0 - F_D)_R$$
$$\Delta R_D = T_D - (R_0 - F_D)_D \qquad (4)$$

where $(R_0\text{-}F_D)_R$ and $(R_0\text{-}F_D)_D$ are connected with the same division coefficients $(A_j)_R$ and $(A_j)_D$ in the form:

$$(R_0 - F_D)_R = (R_0 - F_D)(A_j)_R$$
$$(R_0 - F_D)_D = (R_0 - F_D)(A_j)_D \qquad (5)$$

giving:

$$\Delta R_R = T_R - (R_0 - F_D)(A_j)_R$$
$$\Delta R_D = T_D - (R_0 - F_D)(A_j)_D \qquad (6)$$

The form of the division coefficients $(A_j)_R$ and $(A_j)_D$ is limited to a fraction of the component thrust T_R, T_D or the component P_{DR}, P_{DD} and global thrust or power. All measured values (T_R, T_D, T_{R+D}, T_{R+0}, T_{0+D}, P_{DR}, P_{DD}, $P_{D(R+D)}$, $P_{D(R+0)}$, $P_{D(0+D)}$) are gained from the three possible types of self propulsion tests:

- Test No 1 - the basic test with SR and SD screw propellers in simultaneous action,
  where: T_R, T_D, T_{R+D}, P_{DR}, P_{DD}, $P_{D(R+D)}$ – measured values.
- Test No 2 - the auxiliary test with SR screw propeller only,
  where: T_{R+0}, $P_{D(R+0)}$ – measured values.
- Test No 3 - the auxiliary test with SD screw propeller only,
  where: T_{0+D}, $P_{D(0+D)}$ - measured values.

The different analyzed hypotheses in the form of the division coefficients $(A_j)_R$ and $(A_j)_D$ are given in Tab.1, distinguished by the indices j,(from j = 1 to j = 6).

Tab. 1. *Possible division coefficients $(A_j)_R$ and $(A_j)_D$*

	$(A_j)_R$	$(A_j)_D$
j = 1 thrust ratio	$\frac{T_R}{T_{D+R}}$	$\frac{T_D}{T_{D+R}}$
j = 2 thrust ratio	$\frac{T_R}{T_{0+R}}$	$\frac{T_D}{T_{D+0}}$
j = 3 power ratio	$\frac{P_{DR}}{P_D}$	$\frac{P_{DD}}{P_D}$
j = 4 power ratio	$\frac{P_{DR}}{P_{D(0+R)}}$	$\frac{P_{DD}}{P_{D(D+0)}}$
j = 5 thrust ratio	$\frac{T_R}{T_m}$	$\frac{T_D}{T_m}$
j = 6 power ratio	$\frac{P_{DR}}{P_{Dm}}$	$\frac{P_{DD}}{P_{Dm}}$

THE NECESSARY REQUIREMENTS TO BE MET

From the division coefficients given in Tab. 1 these are to be selected which satisfy two necessary conditions formulated by the author.

Condition No 1:

The sum o the components ΔR_R and ΔR_D calculated by help of the division coefficients $(A_j)_R$ and $(A_j)_D$ is to be equal to the measured global value ΔR_{R+D}:

$$\Delta R_R + \Delta R_D = \Delta R_{R+D} \qquad (7)$$

Condition No 2:

The component ΔR_R and ΔR_D calculated by help of the of the division coefficients $(A_j)_R$ and $(A_j)_D$ - in each of the procedures (i=1 and i=2) - are to be respectively equal to:

$$\Delta R_{R1} = \Delta R_{R2}$$
$$\Delta R_{D1} = \Delta R_{D2} \qquad (8)$$

Theorem No 1:

The division coefficients $(A_j)_R$ and $(A_j)_D$ fulfill the necessary condition No 1 then and only then when the sum of these coefficients is equal to one:

$$(A_j)_R + (A_j)_D = 1 \qquad (9)$$

Proof: Condition No 1 realized in procedure No 1 takes the from:

$$\Delta R_{R1} + \Delta R_{D1} = \Delta R_{R+D}(A_j)_R + \Delta R_{R+D}(A_j)_D = \Delta R_{R+D}[(A_j)_R + (A_j)_D] \qquad (10)$$

The right hand side of this notation is equal to: ΔR_{R+D} only then if $[(A_j)_R + (A_j)_D] = 1$

Condition No 1 realized in procedure No 2 takes the form:

$$\Delta R_{R2} + \Delta R_{D2} = T_R - (R_0 - F_D)_R + T_D - (R_0 - F_D)_D = T_R - (R_0 - F_D)(A_j)_R + T_D - (R_0 - F_D)(A_j)_D = T_R + T_D - (R_0 - F_D)[(A_j)_R + (A_j)_D] \qquad (11)$$

The right hand side of this notation is equal to ΔR_{R+D} only then if: $[(A_j)_R + (A_j)_D] = 1$ because $T_R + T_D - (R_0 - F_D) = T_{R+D} - (R_0 - F_D) = \Delta R_{R+D}$.

Theorem No 2:

The division coefficients $(A_j)_R$ and $(A_j)_D$ fulfill the necessary condition No 2 then and only then if:

$$(A_j)_R = \frac{T_R}{T_{R+D}} \quad \text{and} \quad (A_j)_D = \frac{T_D}{T_{R+D}} \qquad (12)$$

Proof: If ΔR_R is calculated in each of the procedures (i = 1 and i = 2) then one has:

- in procedure No 1:

$$\Delta R_{R1} = \Delta R_{R+D}(A_j)_R \qquad (13)$$

- in procedure No 2:

$$\Delta R_{R2} = T_R - (R_0 - F_D)(A_j)_R \qquad (14)$$

and if both the values are equalized according to the condition No 2 then one receives:

$$\Delta R_{R+D}(A_j)_R = T_R - (R_0 - F_D)(A_j)_R \qquad (15)$$
$$[\Delta R_{R+D} + (R_0 - F_D)](A_j)_R = T_R \qquad (16)$$
$$T_{R+D}(A_j)_R = T_R \qquad (17)$$

$$(A_j)_R = \frac{T_R}{T_{R+D}} \quad (18)$$

If ΔR_D is calculated in each of the procedures (i = 1, i = 2) then one has:

- in procedure No 1:

$$\Delta R_{D1} = \Delta R_{R+D}(A_j)_D \quad (19)$$

- in procedure No 2:

$$\Delta R_{D2} = T_D - (R_0 - F_D)(A_j)_D \quad (20)$$

and if both the values are equalized according to the condition No 2 then one receives:

$$\Delta R_{R+D}(A_j)_D = T_D - (R_0 - F_D)(A_j)_D \quad (21)$$

$$[\Delta R_{R+D} + (R_0 - F_D)](A_j)_D = T_D \quad (22)$$

$$(A_j)_D = \frac{T_D}{T_{R+D}} \quad (23)$$

The necessary condition No 2 with the demand that results of the division should be the same in both the procedures, leads to the statement that the division coefficient must be univocally defined as follows:

$$(A_1)_R = \frac{T_R}{T_{R+D}} \quad ; \quad (A_1)_D = \frac{T_D}{T_{R+D}} \quad (24)$$

Both the coefficients fulfill simultaneously the condition No 1.

CONCLUSIONS

- Among the division coefficients given in Tab. 1, only one pair:

$$(A_1)_R = \frac{T_R}{T_{R+D}} \quad ; \quad (A_1)_D = \frac{T_D}{T_{R+D}} \quad (25)$$

fulfills unconditionally both the necessary conditions:
condition No 1:

$$(A_1)_R + (A_1)_D = 1 \quad (26)$$

condition No 2: $\Delta R_{R11} = \Delta R_{R21}$

$$\Delta R_{D11} = \Delta R_{D21} \quad (27)$$

- The division coefficients $(A3)_R$ and $(A3)_D$, given in Tab. 1 for j = 3, and related to the power:

$$(A_3)_R = \frac{P_{DR}}{P_{D(R+D)}} \quad ; \quad (A_3)_D = \frac{P_{DD}}{P_{D(R+D)}} \quad (28)$$

fulfill the condition no 1:

$$(A_3)_R + (A_3)_D = 1 \quad (29)$$

but they do not fulfill the condition No 2 in general:

$$\Delta R_{R13} \neq \Delta R_{R23}$$
$$\Delta R_{D13} \neq \Delta R_{D23} \quad (30)$$

unless the efficiencies of the screw propellers SR and SD are equal to each other because in this special case only the following is true:

$$\frac{P_{DR}}{P_{D(R+D)}} = \frac{T_R}{T_{R+D}} \quad \text{and} \quad \frac{P_{DD}}{P_{D(R+D)}} = \frac{T_D}{T_{R+D}} \quad (31)$$

- The simplicity of the first procedure makes it generally preferred in practical application.

NOMENCLATURE

F_D	–	the additional towing force
F_{DR}; F_{DD}	–	the parts of F_D being under the influence of the SR and SD propeller, respectively
P_D	–	the total delivered power
$P_{D(0+R)}$	–	the power of the SR propeller only being in action
$P_{D(D+0)}$	–	the power of the SD propeller only being in action
P_{DR}; P_{DD}	–	the power of the SR and SD propeller, respectively, being in simultaneous action
P_{Dm}	–	the algebraic mean value: $P_{Dm} = \frac{P_{D(0+R)} + P_{D(D+0)}}{2}$
R	–	the hull resistance when propelled
R_0	–	the hull resistance when towed
R_{D+R}	–	the hull resistance when propelled by the SR and SD propellers
R_{0+R}	–	the hull resistance when propelled by the SR propeller only
R_{D+0}	–	the hull resistance when propelled by the SD propeller only
R_{0R}; R_{0D}	–	the parts of R_0 being under the influence of the SR and SD propeller, respectively
ΔR	–	the resistance increase due to the propeller action
ΔR_{D+R}	–	the resistance increase due to the simultaneous action of the SR and SD propeller
ΔR_{0+R}	–	the resistance increase due to the SR propeller only being in action
ΔR_{D+0}	–	the resistance increase due to the SD propeller only being in action
ΔR_R; ΔR_D	–	the resistance increase due to the SR and SD propeller, respectively, being in simultaneous action
SD	–	the pulling screw propeller
SR	–	the pushing screw propeller
T_{D+R}	–	the thrust of the SD and SR propeller being in simultaneous action
T_{0+R}	–	the thrust of the SR propeller only being in action
T_{D+0}	–	the thrust of the SD propeller only being in action
T_R; T_D	–	the thrust of the SR and SD propeller, respectively, being in simultaneous action
T_m	–	the algebraic mean value: $T_m = \frac{T_{0+R} + T_{D+0}}{2}$

Acronyms

ITTC – International Towing Tank Conference.

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