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Effective mean velocity (EMV) and effective mean pitch (EMP) based on a common definition

SUMMARY

A definition is given of the effective mean velocity (EMV) in model propulsion test, being simultaneously the definition of effective mean pitch (EMP).

In this way it is possibile to replace the radial pitch distribution of a SB-propeller in behind condition by a constant pitch of a SB_{mod} propeller in an unifrom velocity field with a constant velocity which is the effective mean velocity univocally determined, independent of the averaging criteria (thrust, torque, or power identity).

INTRODUCTION

The effective mean velocity, EMV, widely employed in ship propulsion analysis is recognized to have fundamental defects. First of all the mean value depends upon the subjective selection of the averaging criterion (thrust, torque or power identity). (The power identity criterion was first introduced by H. Jarzyna [6]. F. Horn [7] gave a criterion, identical in form, though without using power in an explicit form).

The same propulsion situation is characterized by three different effective mean values V_T, V_Q, V_P, just as the mean values, V_V, V_M, V_E of an isolated velocity field obtained from the output, momentum and energy identity. It is not possibile to equalize the three different mean values V_V, V_M, V_E when the isolated velocity field is non-uniform.

However, H. Jarzyna [2], [3] has proved that in the case of effective mean velocity it is possible to receive one and only one mean value when the definition of the effective mean velocity is changed appropriately.

The effective mean pitch, EMP, is not yet defined exactly, though in the propeller design practice the „mean pitch" determined as the pitch value of the pitch distribution function at $x = r/R = 0.7$, is used :

$$(P/D)_{mean} = P/D_{(x=0.7)} \tag{1}$$

Though such supposition can be justified from the designer point of view, there is no rational and general justification of it.

This paper resulted from investigations into the definition of an effective mean velocity and thereafter departure from this definition to make the introduction of the effective mean pitch as a definition element possible.

CHARACTERISTICS OF THE PROCEDURE

The new definition of the effective mean velocity (EMV) [1], [2], [3] secures one and only one value of EMV independent of subjective choice of the averaging criterion (thrust, torque or power identity) . The aim of this paper is to present an intentional departure from this definition.

If the present definition of EMV is noted schematically in the form of :

$$SB \cdot FB \leftrightarrow SB \cdot FO \tag{2}$$

then the new definition according to Jarzyna's proposal can be written down as follows :

$$SB_{opt} \cdot FB \leftrightarrow SO_{opt\,j} \cdot FO_j \tag{3}$$

According to the present definition the thrust (torque, or power) of the same SB screw propeller operating in two different velocity fields (the behind velocity field FB and uniform stream FO) is compared giving the effective mean velocity V_T (V_Q or V_P). In general all three values are different ($V_T \neq V_Q \neq V_P$).

According to the new definition two different screw propellers, namely the optimum behind propeller, SB_{opt} in the behind velocity field FB and the optimum open propeller, SO_{opt} in the uniform stream FO, are compared. The same value of EMV: $V_T = V_Q = V_P$ results from the comparison of thrust, torque or power.

A procedure of realization of this definition by means of a step by step method is presented in [8]. The velocity V_{oj} of the FO_j stream is assumed, the optimum open propeller, $SO_{opt\,j}$, is designed and its characteristics

$$K_{TOj} = f(J) \quad \text{and} \quad K_{QOj} = f(J) \tag{4}$$

are determined. The effective mean velocities V_{Tj} and V_{Qj} are received from the thrust identity : $K_{TB} = K_{TOj}$ and torque identity : $K_{QB} = K_{QOj}$. In the $(j + 1)$-th step the velocity $V_{O(j+1)}$ is assumed in such a way that the propeller $SO_{opt(j+1)}$ and its characteristics

$$K_{TO(j+1)} = f(J) \quad \text{and} \quad K_{QO(j+1)} = f(J) \tag{5}$$

as well as $V_{T(j+1)}$ and $V_{Q(j+1)}$ values satisfying the condition

$$| V_T - V_Q |_{(j+1)} < | V_T - V_Q |_j \tag{6}$$

are given.

The limit open propeller is $SO_{opt\ lim}$ and the limit EMV is $V_T = V_Q$.

The question arises how to define the effective mean pitch of a SB_{opt} screw propeller with the radial pitch distribution, $P/D = f(x)$, operating in the behind velocity field FB and being optimum one in these conditions from the efficiency point of view.

Is it possible in such a case to find a constant P/D pitch value of the screw propeller SB_{mod} to satisfy the following two conditions :

$$\underset{\text{in FB}}{(K_{TB})_{SBopt}} = \underset{\text{in FB}}{(K_{TB})_{SBmod}} \tag{7}$$

$$\underset{\text{in FB}}{(K_{QB})_{SBopt}} = \underset{\text{in FB}}{(K_{QB})_{SBmod}} \tag{8}$$

The answer is : it is not possible, from the simple reason that if the screw SB is optimum from the efficiency point of view in the behind velocity field FB, then each other screw in this field FB can not satisfy the torque identity when the thrust identity is valid.

If

$$\underset{\text{in FB}}{(K_{TB})_{SBopt}} = \underset{\text{in FB}}{(K_{TB})_{SBmod}} \tag{9}$$

then

$$\underset{\text{in FB}}{(K_{QB})_{SBopt}} < \underset{\text{in FB}}{(K_{QB})_{SBmod}} \tag{10}$$

The question is open how to define the effective mean pitch to make its realization possible.

Is it possible to choose P/D = const for the screw propeller SB_{mod} in the stream FO to satisfy two conditions ?

$$\underset{\text{in FB}}{(K_{TB})_{SBopt}} = \underset{\text{in FO}}{(K_{TO})_{SBmod}} \tag{11}$$

$$\underset{\text{in FB}}{(K_{QB})_{SBopt}} = \underset{\text{in FO}}{(K_{QO})_{SBmod}} \tag{12}$$

The answer is positive if the velocity of the stream FO will be determined simultaneously and univocally.

The proof of this statement is simple if the above presented new definition of EMV is modified to introduce and to join in one definition the effective mean velocity (EMV) and the effective mean pitch (EMP) both univocally valued and simultaneously determined :

$$SB_{opt} \cdot FB \leftrightarrow SB_{mod\,j} \cdot FO \tag{13}$$

This notation can be read as follows.

Two different propellers are proposed to be compared. These propellers are related to each other in such a way that only the radial pitch distributions are different. The radial pitch distribution of the SB_{opt} propeller is known. The constant pitch of the SB_{mod} propeller is to be found. The procedure of joining the EMV and EMP is described hereafter.

The pitch $(P/D)_j$ is selected and the characteristics $K_{TOj} = f(J)$; $K_{QOj} = f(J)$ of the propeller $SB_{mod\,j}$ are determined. The effective mean velocities V_{Tj} and V_{Qj} are found from the thrust or torque identity by using the experimental or calculated values of K_{TB} and K_{QB}.

The value $(P/D)_{j+1}$ satisfying the condition :

$$| V_T - V_Q |_{(j+1)} < | V_T - V_Q |_j \tag{14}$$

is chosen.

The limit of the sequence $(P/D)_j$ is equal to $(P/D)_{lim}$.

The limits of the sequences V_{Tj} and V_{Qj} are equal to one and only one value $V_T = V_Q$.

Different results are received when K_{TB} and K_{QB} values from experiment or from calculation are used in two different procedures (procedure no 3.3 or 3.4).

What is the sense of such a definifion of the effective mean pitch combined with the effective mean velocity ?

If the assumption is made that the EMV $(V_T = V_Q = V_{TQ})$ and the EMP $(P/D$ = const) was determined by using the above given method then the screw SB_{mod} with P/D = const operating in FO with $V_O = V_T = V_Q = V_{TQ}$ can be applied to calculate $(K_{TO})_{SBmod}$ and $(K_{QO})_{SBmod}$ which are equal to $(K_{TB})_{SBopt}$ and $(K_{QB})_{SBopt}$ of the screw SB_{opt} operating in FB.

It means that the screw SB_{opt} in FB can be replaced by the screw SB_{mod} with P/D = const in FO with $V_O = V_T = V_Q = V_{TQ}$ but only when K_T, and K_Q coefficients are to be calculated.

ANALYSIS OF CALCULATION RESULTS

The new method of simultaneous and univocal determination of the effective mean velocity (EMV) and effective mean pitch (EMP) from a common definition is presented by means of numerical simulation results. Results of the model propulsion tests BN18 bis were the basic input data to the calculation procedures.

The calculation results according to both procedures no 3.3 and no 3.4 are presented in Tab.1, 2 and 3 and in Fig.1, 2, and 3.

In each of these two procedures the constant pitch of the screw propeller SB_{mod}, being the effective mean pitch of the SB_{102} screw propeller used in the model propulsion tests BN18 bis, is to be found. The simultaneous condition that the effective mean velocities from the thrust and torque identities should be equal and moreover the thrust and torque coefficients of both propellers should be equal :

$$(K_{TB})_{SB102} = (K_{TB})_{SBmod} \tag{15}$$

$$(K_{QB})_{SB102} = (K_{QB})_{SBmod} \tag{16}$$

is to be satisfied.

Tab.1. *Procedure 3.3. The input and output data*

$K_{TB} = 0.191$ $n = 8.42$ [s] $V_m = 2.222$ [ms]
$K_{QB} = 0.02885$ $D = 0.278$ [m] $t = 0.217$

J	0.5	0.55	0.6	0.65	0.7
K_{TO}	0.22390	0.20142	0.17796	0.15354	0.12814
K_{QO}	0.03279	0.03012	0.02734	0.02444	0.02141
η_0	0.54339	0.58539	0.62160	0.64993	0.66681
K_I	- 0.03290	- 0.01042	0.01304	0.03746	0.06286
$-K_{II}$	0.04951	0.01451	- 0.01581	- 0.04263	- 0.06678

Parameters and calc. values	Averaging criterion		
	thrust	power	torque
J	0.57246	0.57288	0.57321
$\frac{V}{V_m} = J \cdot 1.0534473$	0.60306	0.60350	0.60384
K_{TO}	0.191	0.19080	0.19065
K_{QO}	0.02889	0.02886	0.02884
$\eta_0 = \frac{K_{TO}}{K_{QO}} \cdot \frac{J}{2\pi}$	0.60246	0.60276	0.60300
$\eta_H = \frac{1-t}{V/V_m}$	1.29838	1.29743	1.29670
$\eta_R = \frac{\frac{K_{TB}}{K_{TO}}}{\frac{K_{QB}}{K_{QO}}}$	1.00125	1.00147	1.00164
$\eta_D = \eta_0 \cdot \eta_H \cdot \eta_R$	0.78319	0.78319	0.78319
P/D	0.8700		

***Tab.2.** Procedure 3.4. The input and output data*

$K_{TB} = 0.189979$ n = 8.42 [s] $V_m = 2.222$ [ms]
$K_{QB} = 0.02885$ D = 0.278 [m] t = 0.217

J	0.5	0.55	0.6	0.65	0.7
K_{TO}	0.22595	0.20353	0.180136	0.15577	0.13044
K_{QO}	0.03319	0.03052	0.02772	0.02481	0.02178
η_0	0.54176	0.58377	0.62055	0.64954	0.66724
K_I	- 0.03616	- 0.01374	0.00966	0.03402	0.05935
$- K_{II}$	0.05454	0.01908	- 0.01183	- 0.03905	- 0.06346

Parameters and calc. values	Averaging criterion		
	thrust	power	torque
J	0.57961	0.57991	0.58014
$\frac{V}{V_m} = J \cdot 1.0534473$	0.61059	0.61091	0.61115
K_{TO}	0.18979	0.18965	0.18954
K_{QO}	0.02888	0.02886	0.02885
$\eta_0 = \frac{K_{TO}}{K_{QO}} \cdot \frac{J}{2\pi}$	0.60634	0.60656	0.60673
$\eta_H = \frac{1-t}{V/V_m}$	1.28238	1.28170	1.28119
$\eta_R = \frac{\frac{K_{TB}}{K_{TO}}}{\frac{K_{QB}}{K_{QO}}}$	1.00088	1.00104	1.00116
$\eta_D = \eta_0 \cdot \eta_H \cdot \eta_R$	0.77823	0.77823	0.77823
P/D	0.8742		

***Tab.3.** The specification of EMV and EMP from one of the model propulsion tests BN18 bis*

Procedure symbols	$\frac{P}{D}$	$\frac{V_T}{V_m}$	$\frac{V_Q}{V_m}$	$\frac{V_P}{V_m}$	K_{TB}	K_{QB}
3.3	0.8700	0.6031	0.6038	0.6035	0.1910	0.02885
3.4	0.8742	0.6106	0.6112	0.6109	0.1900	0.02885

In j-th step of each of these procedures two equations being the result of comparison of thrust and torque of the propellers SB_{102} and SB_{mod_j} with the pitch coefficient $(P/D)_j$ are solved.

In the two procedures the source of K_{TB} and K_{QB} coefficient of the SB_{102} propeller is different (experiment or calculation) :

$$\left.\begin{aligned}(K_{TB})_{exp} &= K_{TOj}(J) \rightarrow J_{T3.3j}\\ (K_{QB})_{exp} &= K_{QOj}(J) \rightarrow J_{Q3.3j}\end{aligned}\right\}\text{procedure } 3.3 \qquad (17)$$

$$\left.\begin{aligned}(K_{TB})_{calc} &= K_{TOj}(J) \rightarrow J_{T3.4j}\\ (K_{QB})_{calc} &= K_{QOj}(J) \rightarrow J_{Q3.4j}\end{aligned}\right\}\text{procedure } 3.4 \qquad (18)$$

The selection of the pitch $(P/D)_{j+1}$ in the $(j + 1)$-th step in both procedures is carried out to satisfy the condition :

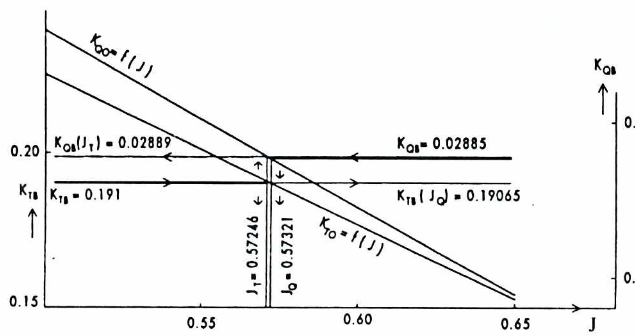
$$| J_T - J_Q |_{(j+1)} < | J_T - J_Q |_j \qquad (19)$$

The limit value of P/D of the screw SB_{mod} and simultaneously the equality of J_T and J_Q from the thrust and torque identities is received as shown in Tab.1, 2 and 3.

In Fig.1 and 2 the determination of the limit values of J_T, J_Q and J_P according to the thrust, torque, and power identities is presented. The data to draw the curves $K_I = f(J)$ and $(- K_{II}) = f(J)$ are given in Tab.1 and 2. The effective mean pitch, EMP, can be found in Tab.1 and 2. The specification of EMV and EMP values from BN18 bis tests is given in Tab.3.

The explanations to author's method of V_P determination from power identity can be found in [6] and [7].

a)



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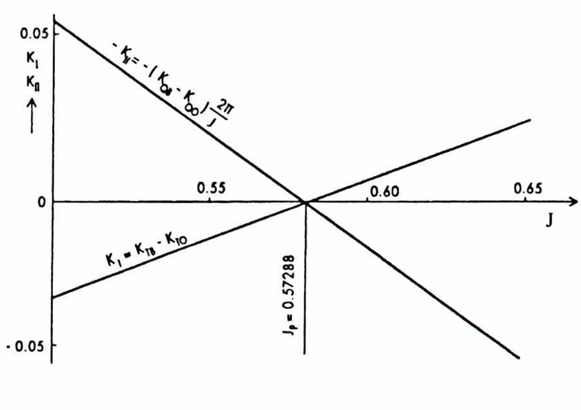
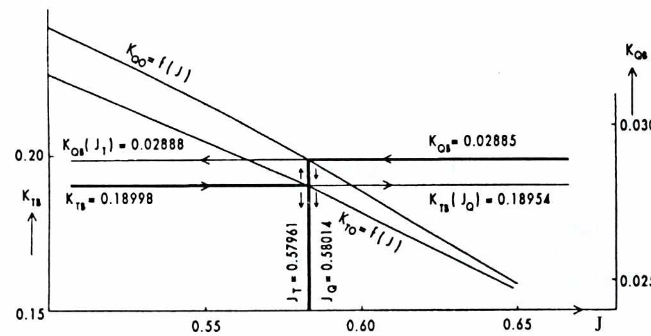


***Fig.1.** Effective mean velocity determination in procedure 3.3*
a) thrust and torque criterion b) power criterion

a)



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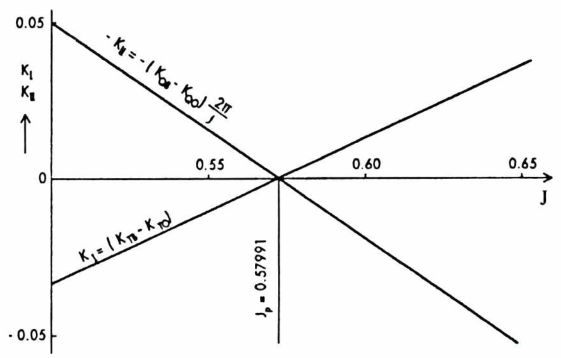

Fig.2. Effective mean velocity determination in procedure 3.4
a) thrust and torque criterion b) power criterion

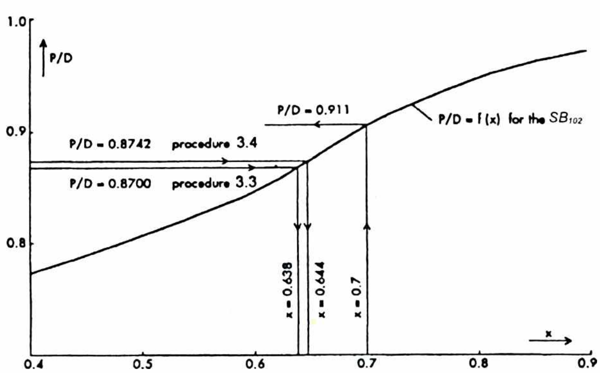

Fig.3. The effective mean pitch obtained from procedure 3.3 and 3.4.

CONCLUSIONS

- Determination of the effective mean velocity (EMV) and the effective mean pitch (EMP) of the behind screw propeller from a common definition is possible.
- Further investigation into the relation between the effective mean pitch (EMP) and the pitch at the radius x = 0.7 could be of interest to propeller designers.
- It will be valuable to include the determination of the effective mean pitch (EMP) to the standard practice of model propulsion test when the effective mean velocity, EMV, resulting from the definition common with the EMP is accepted. There are no rational reasons why this acceptance could not be given.

NOMENCLATURE

D - screw diameter, $D=2R$
EMP - effective mean pitch
EMV - effective mean velocity
FB - behind velocity field
FO - uniform stream
J - advance coefficient, $J = V/nD$
J_Q - advence coefficient related to torque identity
J_T - advence coefficient related to thrust identity
K_Q - torque coefficient, $K_Q = \frac{Q}{\rho n^2 D^5}$
K_T - thrust coefficient, $K_T = \frac{T}{\rho n^2 D^4}$
K_{QB} - torque coefficient of the behind propeller
K_{TB} - thrust coefficient of the behind propeller
K_{QO} - torgue coefficient of the open propeller
K_{TO} - thrust coefficient of the open propeller
P - screw propeller pitch
Q - torque
R - screw radius, $R=D/2$
SB - behind screw propeller
SB_{102} - propeller used in the model tests BN 18 bis
SO - open screw propeller
T - thrust
V - velocity
V_E, V_M, V_V - mean velocity from energy, momentum and volumen, respectively
V_e - effective velocity
V_m - model ship velocity
V_o - velocity of the FO stream
V_P - EMV from power identity
V_Q - EMV from torque identity
V_T - EMV from thrust identity
V_{TQ} - EMV from the new procedure
n - number of revolutions per second
r - radial coordinate
t - suction coefficient
x - dimensionless radial coordinate, $x = r/R$
η_D - propulsive efficiency
η_H - „hull efficiency”
η_O - open screw efficiency
η_R - „relative rotating efficiency”.
ρ - water density

Indices

calc - calculation
exp - experiment
j - step number in iterative process
lim - limit
mod - modified version
opt - optimum version

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