HENRYK JARZY
Polish Academy of Sciences
Institute of Fluid Flow Machinery, Gdańsk
Ship Propeller Department

The reasons to introduce a new definition of the effective mean velocity in model propulsion tests

Part I

SUMMARY

The essence of the effective mean velocity definition is analysed by the author. This definition is indivisibly connected with the effective velocity field being in interaction with the ship screw propeller.

The effective mean velocity is set against the mean value of the isolated effective velocity field. The differences in the relations between criterional quantities in the averaging process in both cases are specified.

These differences make the necessity of introduction of a new effective mean velocity definition to the model propulsion tests and to the numerical simulation procedures well justified.

INTRODUCTION

Is it not controversial, that so much attention is paid to a such prosaic idea as the mean velocity seems to be?

One could agree with this opinion, if in the literature a clear differentiation between the mean velocity of a velocity field and the effective mean velocity from model propulsion tests in ship hydrodynamics could be found

Unfortunately one can not find in the literature a clear statement what is the difference between these two types of mean velocities. On the contrary one can find very often that the effective mean velocity from model propulsion tests is uncritically compared with the mean velocities of the effective velocity field from numerical determination. The question arises what value of the two values possible but different from model tests should be compared with one of the three possible values from calculation when analysing the isolated effective velocity field.

In the literature one can find only the comparison of the effective mean velocity from thrust identity with the mean velocity from output identity. The authors of such comparisons are satisfied when they can conclude that these two values agree. But this can happen only when the velocity field is very close to a uniform one.

There are some questions connected with different averaging processes, which are to be answered. First of all some rules of the mean value determination of an isolated velocity field should be reminded. Different criteria can be used and different mean values are the result.

All these mean velocities are equivalent to some limitation needed in practice. Only the criterional quantity can be determined using the mean velocity. All noncriterional quantities calculated with the help of the mean velocity are to be corrected. It is not always possible to find the correction factor. This fact must be accepted. It is not possible to try to equalize these different values of the mean velocity.

The same situation is observed in the case of different values of the effective mean velocity. Two examples can be given where the correction factor is easy to be found. The first one is the determination of the torque coefficient when the thrust identity is used in mean velocity designation:

$$K_{QB} = K_{Q0}(J_T) \cdot \frac{K_{QB}}{K_{Q0}(J_T)} , \qquad (1)$$

where the correction factor is in direct relation to the well known in ship hydrodynamics relative rotative «efficiency» η_R^T :

$$\eta_R^T = \frac{1}{\frac{K_{QB}}{K_{Q0}(J_T)}} . \qquad (2)$$

The second example is the correction factor in the thrust coefficient determination, when the torque identity is used in the averaging process:

$$K_{TB} = K_{T0}(J_Q) \cdot \frac{K_{TB}}{K_{T0}(J_Q)} . \qquad (3)$$

The correction factor is related to the relative rotating «efficiency» η_R^Q :

$$\eta_R^Q = \frac{K_{TB}}{K_{T0}(J_Q)} . \qquad (4)$$

Some cases are to be particularized now where it is not possible to find the right correction factor and where the noncriterional quantities are different when determined using different mean velocities.

One can mention first of all the efficiency of the behind propeller defined as:

$$\eta_B = \frac{K_{TB}}{K_{QB}} \cdot \frac{J_A}{2\pi} , \qquad (5)$$

where J_A is in relation to the effective mean velocity v_T or v_Q depending on what averaging criterion is used.

These two different mean values give two different values of the efficiency of the behind propeller being in the same conditions:

$$\eta_B^T = \frac{K_{TB}}{K_{QB}} \cdot \frac{J_T}{2\pi}, \quad (6)$$

or

$$\eta_B^Q = \frac{K_{TB}}{K_{QB}} \cdot \frac{J_Q}{2\pi}. \quad (7)$$

Is it possible or is it allowable that a physical quantity such as the propeller efficiency could be different in the same operation conditions due to the subjective choice of the averaging criteria only?

Another noncriterional quantity which can not be corrected is the hull «efficiency» η_H and the relative rotative «efficiency» η_R. When the thrust or torque criterion is applied in effective mean velocity determination one will receive $\eta_H^T \neq \eta_H^Q$ or $\eta_R^T \neq \eta_R^Q$.

The effective mean velocity is the result of interaction between the effective velocity field and the ship propeller. The cases when it is not possible to find the right correction factor are often of primary meaning in the practical design problems in ship hydrodynamics. The possibility of univocal determination of such values is therefore of primary significance.

The author has given in his paper [1] the new definition of effective mean velocity. The result of this definition is the univocal determination of the mean velocity independent of the averaging criterion used. The result is also the univocal determination of all noncriterional quantities dependent on this mean velocity.

In this paper the necessity of introduction of this definition to the practice of model propulsion tests will be justified and the argumentation will be deepened.

THE MEAN VELOCITY OF THE ISOLATED VELOCITY FIELD

The idea of the mean velocity of an isolated velocity field can be realized when a selected quantity (output, momentum, energy) determined in the nonuniform and in the uniform velocity field is identical. The mean velocity needed is then calculated from this identity.

The definition of the mean value of an an isolated velocity field can be noted as:

$$FB \to FO. \quad (8)$$

When the averaging area is the screw propeller disk, $x_H \leq x \leq 1$, $x = r/R$, the three mentioned mean velocities, according to this definition can be given as:

$$\left(\frac{v}{v_S}\right)_V = \frac{2}{1-x_H^2} \int_{x_H}^{1} \frac{v}{v_S}(x) x dx \quad (9)$$

$$\left(\frac{v}{v_S}\right)_M^2 = \frac{2}{1-x_H^2} \int_{x_H}^{1} \left[\frac{v}{v_S}(x)\right]^2 x dx \quad (10)$$

$$\left(\frac{v}{v_S}\right)_E^3 = \frac{2}{1-x_H^2} \int_{x_H}^{1} \left[\frac{v}{v_S}(x)\right]^3 x dx \quad (11)$$

where v_V, v_M, v_E - the mean velocities due to the output, momentum and energy identity, respectively.

This free selected quantity being equalized in both fields is defined as the criterional quantity. All other quantities being in connection with the nonuniform velocity field are the noncriterional quantities.

Different criterional quantities give different mean velocities though the velocity field and the averaging areas are the same. It is easy to prove that the relation:

$$v_V < v_M < v_E \quad (12)$$

is always satisfied in nonuniform velocity field.

According to the relations (9), (10) and (11) only the criterional quantity can be determined with the help of the mean velocity, without any correction. Each noncriterional quantity can be calculated using the mean velocity, if only a correction factor is introduced.

When e.g. the energy, is to be determined by means of v_V, a correction factor α_E is to be used:

$$E_r = E_\alpha \cdot \alpha_E \quad (13)$$

where:

E_r - the real energy,

E_a - the apparent energy according to v_V,

α_E - energy correction factor.

In a pipe flow, e.g., the energy correction factor can be equal $\alpha_E = 2$ in the case of a laminar flow and equal $\alpha_E \cong 1$ in the case of turbulent flow.

One can prove that different mean velocities due to different averaging criteria are all justified if only the proper correction factors is used in noncriterional quantity determination with the help of the mean velocity.

EFFECTIVE MEAN VELOCITY

Different velocity fields are defined in Ship Hydrodynamics.

The velocity field behind the ship hull towed without the screw propeller is called *the nominal velocity field.*

The total velocity field is the one measured just before or just behind the screw propeller being in action.

The induced velocity field is one which is generated (e.g.) by the vortex system modelling the screw propeller.

The effective velocity field is an hypothetical, imaginary velocity field. It can be determined from the measured nominal velocity field or from the measured total velocity field taking into account the deformation effects due to the propeller action.

In the case when the nominal velocity field is the starting point in the effective velocity field determination, the mentioned deformation is the change of the flow about the hull caused by the propeller.

In the case when the total velocity field is used, the induced velocity field must be subtracted from the total velocity field to receive the effective velocity field. The effective velocity field is not measurable. It is the starting point in screw propeller design. But even the best computer design programs will not be able to ensure the needed reliable calculation results if the effective velocity field is not determined with the needed accuracy. The verification methods of the procedures of effective velocity fields determination are therefore so much wanted.

In relation to the fact that the effective velocity field can not be measured directly only the indirect methods of verification can be taken into account.

One such partial verification method is known to day. It is the possibility to determine the effective mean value in model propulsion tests.

The idea of the effective mean velocity is therefore of great importance. The investigations in this area are needed and are in no way of second rank.

The logical structure of the idea of the effective mean velocity is quite different from that of the mean velocity of the effective velocity field.

The idea of the effective mean velocity is in strong connection with the interaction process between the velocity field and the screw propeller. The values resulting from this interaction, such as thrust, torque or power, are selected to be the criterional values in the averaging procedures.

Different criteria give different effective mean velocities. The differences between them depend not only upon the nonuniformity of the velocity field but also upon the effects of the interaction of the velocity field and the screw propeller.

The realization of the thrust identity criterion, e.g., is grounded on the requirement that the thrust of the screw *SB* in the field *FB* is to be equal to the thrust of the screw *SO* in the field *FO* with unknown constant velocity v_T. This velocity v_T is determined from the thrust-identity and is defined as the effective mean velocity. The torque-identity criterion gives accordingly another effective mean velocity v_Q.

The question to be answered now is what will be the relations between v_T and v_Q in a given velocity field *FB* if the geometry of the screw *SB* and *SO* is changed.

One can state in general, that the thrust of the screws *SB* with different geometry in the velocity field *FB* will be different. The thrust of the screws *SO* in the field *FO* will be related to the *FO* screw geometry and to the unknown velocity of the uniform stream.

The effect of thrust or torque identity of the screw *SB* in *FB* and the screw *SO* in *FO* field will be a sequence of effective mean velocities v_T and v_Q.

The relation between v_T and v_Q in each pair of this sequence will be different in very broad limits. One can prove that for a given velocity field *FB* and different geometry of the screw *SB* and *SO* all possible relations between v_T and v_Q can occur:

$$v_T < v_Q \quad (14)$$

$$v_T > v_Q \quad (15)$$

$$v_T = v_Q \quad (16)$$

The fundamental difference between the idea of the effective mean velocity and the idea of the mean velocity of an isolated effective velocity field is to be connected with the different relations between the mean values determined with the help of different averaging criteria.

In the case of mean velocities of an isolated velocity field the relation (12) is always valid whatever the nonuniformity of the velocity field may be. It is not possible to change the relation (12).

In the case of effective mean velocity one has the possibility to influence the choice of the screw *SB* and *SO* in such a way, that each of the relations (14), (15) or (16) can be realized.

In model propulsion tests realized according to the present-day requirements some limitations of the geometry of the screw *SB* and *SO* are used. The screw *SB* is the optimum behind screw, SB_{opt}. The *SO* screw is the same SB_{opt} screw. The definition of the effective mean velocity in this case is therefore related to the thrust or torque identity of the same screw in the nonuniform *(FB)* and in the uniform *(FO)* stream. This definition will be denoted with number one. The effective mean velocities v_T and v_Q are satisfying the relation (14) - $v_T < v_Q$. The averaging procedure can be noted formally as:

$$SB_{opt} \times FB \rightarrow SB_{opt} \times FO \quad (17)$$

An hypothetical case could be assumed where the effective mean velocity is determined in a procedure:

$$SO_{opt} \times FB \rightarrow SO_{opt} \times FO \quad (18)$$

Here the optimum screw in *FO*, SO_{opt}, is working in both fields, *FB* and *FO*, giving v_T and v_Q according to the thrust or torque identity being in relation $v_T > v_Q$.

In the model propulsion tests practice a stock propeller is often used. The stock propeller is a screw propeller not designed specially but chosen from the screws in store-room. Some criteria must be fulfilled when the right stock propeller is to be selected. The screw diameter must be the same, the pitch ratio deviation should be not greater than ± 15 %. The blade number must be the same.

The procedure of effective mean velocity determination can be written down in this case as:

$$SB_m \times FB \rightarrow SB_m \times FO \quad (19)$$

The common element of the procedures (17), (18) and (19) is the same screw used in both fields *FB* and *FO*. From the model propulsion tests with stock propeller one can state that both relations (14) and (15) between v_T and v_Q are to be observed. It is so because in the case where $v_T < v_Q$ the screw SB_m is closer to SB_{opt} in procedure (17) and in the case $v_T > v_Q$ the crew SB_m is closer to SO_{opt} in procedure (18).

From the comparison of two procedures (17) and (18) one can conclude, that a new procedure could be built:

$$SB_{opt} \times FB \rightarrow SO_{opt} \times FO \quad (20)$$

to satisfy the relation (16):

$$v_T = v_Q = v_{TQ}$$

Two different screw propellers are used in realizing the procedure (20). Each of these two screw propellers is optimum in its velocity field: SB_{opt} in *FB* and SO_{opt} in *FO*.

The definition 2 of the effective mean velocity is based upon the assumption that the mean value should be determined from the thrust or torque equality of two screw propellers one of which is optimum in the velocity field *FB* and the other one is optimum in the field *FO*. The general result of this definition 2 is that the mean velocity is the same whatever averaging criterion is used: the thrust or the torque identity.

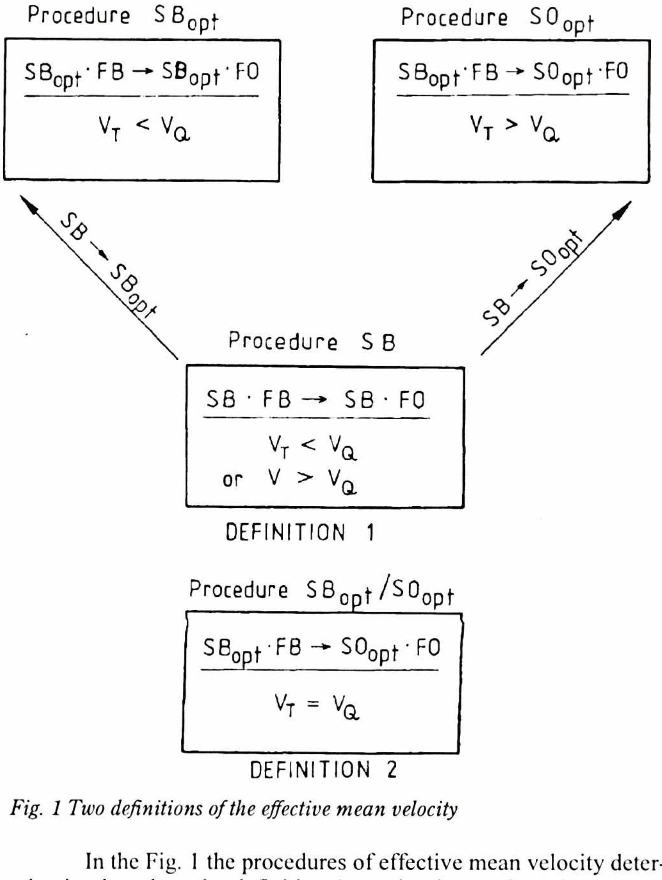

Fig. 1 Two definitions of the effective mean velocity

In the Fig. 1 the procedures of effective mean velocity determination based on the definition 1, used today, and on the actually proposed definition 2 are presented. The procedure SB_{opt} is the fundamental one based on the definition 1. It will be always realized in model propulsion tests if only the design and manufacture of the SB_{opt} screw is possible. When not possible, the procedure *SB* is used with the screw *SB* being a stock propeller. The procedure *SB* is of course based on the definition 1.

The procedure SB_{opt}/SO_{opt} is based on the new proposed definition 2. The last procedure SO_{opt} , based on the definition 1 and given in the Fig. 1, is an hypothetical one, out of practical value, and only presented to give a full picture of the problems connected with the definition 1 and to better justify the generation of the idea of the definition 2.

All what was said above is the reason why it is needed to introduce a new definition of the effective mean velocity.

In model propulsion tests practice only the definition 1 is used to determine the effective mean velocity. This mean velocity is most often applied to determine some global characteristics of the screw propeller in behind condition such as propulsion efficiency η_D , the efficiency η_B of the behind screw propeller, the hull efficiency η_H or the relative rotating efficiency η_R .

The propulsion efficiency is independent of the effective mean velocity. This is evident from the definition:

$$\eta_D = \frac{K_{TB}}{K_{QB}} \frac{J_S}{2\pi} (1-t) \cdot \tag{21}$$

In design practice this quantity is determined often in another way:

$$\eta_D = \frac{R_O \cdot v_S}{Q_B \cdot \omega_B} = \frac{T_B(1-t) \cdot v_S}{Q_B \cdot \omega_B} = \frac{\frac{T_B}{T_O} T_O (1-t) \cdot v_S}{\frac{Q_B}{Q_O} Q_O \cdot 2\pi\eta_B} \tag{22}$$

$$= \frac{K_{TO}}{K_{QO}} \cdot \frac{J_A}{2\pi} \cdot \frac{\frac{K_{TB}}{K_{TO}}}{\frac{K_{QB}}{K_{QO}}} \cdot \frac{1-t}{\frac{v_A}{v_S}} \tag{23}$$

$$= \eta_0 \cdot \eta_R \cdot \eta_H \cdot \tag{24}$$

The velocity v_A in (23) is the effective mean velocity, which is different when different averaging criteria are used. One can have therefore:

$$\eta_D = \eta_{0T} \cdot \eta_{RT} \cdot \eta_{HT} \tag{25}$$

$$= \eta_{0Q} \cdot \eta_{RQ} \cdot \eta_{HQ} \cdot \tag{26}$$

The same value of η_D can be determined by the same value of the product of three different factors:

$$\eta_{0T} \neq \eta_{0Q} \tag{27}$$

$$\eta_{RT} \neq \eta_{RQ} \tag{28}$$

$$\eta_{HT} \neq \eta_{HQ} \cdot \tag{29}$$

One can state that the different effective mean velocities being the consequence of different averaging criteria used, v_T or v_Q, do not influence the propulsion efficiency. Whatever the difference between v_T and v_Q may be the propulsion efficiency is always the same when only the K_{TB}, K_{QB}, J_S and t is the same.

Another situation will be when the second quantity, the behind screw propeller efficiency η_B is analyzed. The definition of η_B is:

$$\eta_B = \frac{K_{TB}}{K_{QB}} \cdot \frac{J_A}{2\pi} = \eta_O \cdot \eta_R \cdot \tag{30}$$

When different values of v_A are used one can have :

$$\eta_{BT} \neq \eta_{BQ} \quad \text{, because} \quad \eta_{OT} \cdot \eta_{RT} \neq \eta_{OQ} \cdot \eta_{RQ} \,.$$

It means that the same screw propeller in the same behind conditions can show different efficiency if only the averaging criterion is changed. The behind screw propeller efficiency is a physical quantity and it is not permissible that it be a subjective quantity.

The same can be said about η_O, η_H and η_R when each of these quantities is analysed separately.

Therefore the question should be answered if it is necessary to use the definition 1 in effective mean velocity determination despite of all the negative consequences. Does such a necessity exist ? If not, one could not find any obstacle to introduce the actually proposed definition 2 to the model propulsion test pratice, the definition which does not generate all the consequences connected with the definition 1.

One could give the following argumentation for the definition 1. The behind screw is generating the thrust T_B. The question arises if it is possible that the same screw will generate the same thrust T_B in uniform stream with the velocity v_T which is to be determined. The answer is positive. The only trouble is that the answer is not univocal. One receives two different values v_T and v_Q. It could seem that there is the same phenomenon which is observed in the averaging process of an isolated velocity field, where the mean values resulting from different averaging criteria are all equivalent. The general difference between these cases is already described above. In the case of an isolated velocity field it would not be possible to change the relation given in (12):

$$v_V < v_M < v_E ,$$

if the uniformity factor was not changed.

In the case of the velocity field being in interaction with the screw propeller one has the possibility to change the relation between v_T and v_Q for the same velocity field when different screw propellers are used in both velocity fields, F_B and FO. One has the possibility to select the screw propeller in FO in such a way that v_T will be equal v_Q.

This valuable difference between the averaging process of an isolated velocity field and the determination of the effective mean velocity of the velocity field being in interaction with the screw propeller will be described in particular.

Let the procedure:

$$SB_{opt} \times FB \rightarrow SB_{opt} \times \times FO \tag{17}$$

be analysed (Fig. 2).

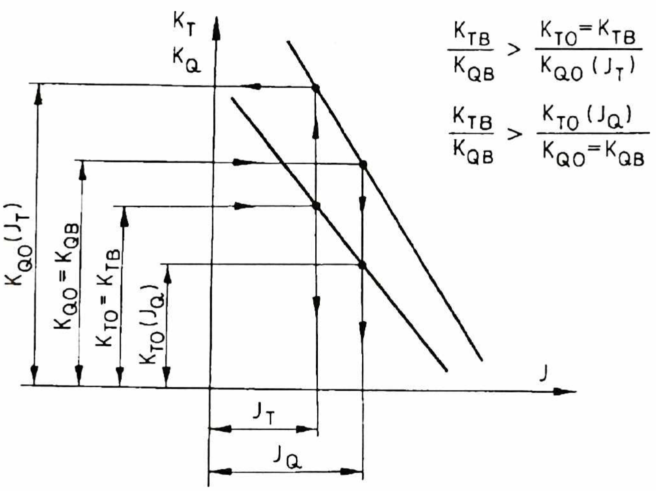

Fig. 2. Determination of v_T and v_Q according to the procedure $SB_{opt} \times FB \rightarrow SB_{opt} \times FO$

If the SB_{opt} screw is an optimum one in the field FB, then it is worse adapted to the action in the uniform field velocity.

If the thrust identity of the screw SB_{opt} in FB and FO is assumed and this identity is observed when the velocity of the stream FO is v_T one can state that:

$$K_{TB} = K_{TO}(J_T) \tag{31}$$

and simultaneously:

$$K_{QO}(J_T) > K_{QB} \,. \tag{32}$$

The torque identity of the screw SB_{opt} in FB and FO gives:

$$K_{QB} = K_{QO}(J_Q) \quad (33)$$

$$K_{TO}(J_Q) < K_{TB} . \quad (34)$$

It means that in the case of the procedure (17) one has always:

$$J_T < J_Q \text{ or } v_T < v_Q . \quad (14)$$

The K_{TB} and K_{QB} values are resulting from the model propulsion tests or from calculation based on the numerical simulation method.

From (31) and (32) or from (33) and (34) one can deduce that the ratio K_T/K_Q satisfies the relation:

$$\frac{K_{TB}}{K_{QB}} > \frac{K_{TO}}{K_{QO}} \quad (35)$$

irrespective of the averaging criterion used in realizing the procedure (17).

If similar relation to (35) is to be built using the procedure (19) one must differentiate two cases, when the screw SB is better adapted to the velocity field FB or the field FO. In the first case the relation (35) will be valid, in the second case the relation:

$$\frac{K_{TB}}{K_{QB}} < \frac{K_{TO}}{K_{QO}} \quad (36)$$

can be deduced.

The question arises if it is possible to acquire the equality :

$$J_T = J_Q \quad (37)$$

$$v_T = v_Q \quad (38)$$

and what are the conditions to realize the result wanted.

It has been proved that the relation (37) and (38) could be realized if only the definition of effective mean velocity had been changed.

The essence of this new definition is the demand that the effective mean velocity is the same irrespective of the averaging criterion used. The necessary condition is that two different screw propellers are to be compared in two different velocity fields. The optimum screw propeller SB_{opt} in FB velocity field must be compared with the optimum screw propeller SO_{opt} in the field FO.

The thrust identity and the torque identity of these two screws gives the same effective mean velocity according to the procedure (20):

$$SB_{opt} \times FB \rightarrow SO_{opt} \times FO . \quad (20)$$

One can recapitulate the last considerations as follows. In the case when the definition 1 of the effective mean velocity and consequently the procedure SB_{opt} is used the thrust or torque of the same screw SB_{opt} in two different velocity fields FB and FO is compared. In consequence two different mean values v_T and v_Q are resulting. The thrust (or torque) is produced in different conditions, which are not comparable. The SB_{opt} is working in the field FB in its optimum conditions. The SB_{opt} is no more in optimum conditions when it is working in the field FO.

In the case of definition 2 and the procedure SB_{opt}/SO_{opt} two different screw propellers are taken into account each of them being optimum in its flow conditions: SB_{opt} in the field FB and SO_{opt} in FO. One can say that both propellers are working in comparable conditions.

The question if it is necessary to use the definition 1 and to apply the same screw propeller in both fields FB and FO must be answered negatively. The definition 2 should be therefore accepted without difficulties. The numerical realization of the procedure SB_{opt}/SO_{opt} is always possible and has been verified. The realization of the experimental procedure should be developed. In author's opinion it is possible to overcome difficulties in construction of such procedures.

The definition 1 leads to different effective mean velocities according to the different averaging criteria. The definition 2 gives a univocal answer. The question is which of these mean values is the right one, the value from definition 1 based on a single optimum screw or the one from definition 2 based on two optimum screw propellers. It would be easier to answer this question if one first could decide which of the possible different mean values according to the definition 1 (v_T, v_Q, v_P) is the right one. There is no answer. One can only state, that each of these values is allowable if it is used according to the conditions connected with the determination procedure.

The problem arises when a quantity can be determined being a function of the mean value. If it is a physical quantity one has a serious trouble how to determine the quantity, univocal from physical nature, using different mean values which are all equivalent.

The only solution is to accept the new proposed definition 2 to receive the univocal result in mean value determination and to secure that physical quantities will be determined univocally.

It is an open problem what changes are to be introduced to the methods of ship model propulsion tests to realize in practice the new definition 2.

Research work to solve this problem has been defined in a new research project proposal submitted to KBN (The Scientific Research Committee) for the years 1995 -1996.

Numerical research work is already carried out appylying the author's numerical simulation method. Comparison between the results according to both definitions will be given in the Part II of the paper. *(to be continued)*

BIBLIOGRAPHY

1. Jarzyna H. , Tuszkowska-Koronowicz T. , Młynarczyk J. , Jaworski S. : «Wzajemne relacje efektywnych prędkości średnich z numerycznej symulacji i modelowych badań napędowych » (The relations between the effective mean velocities from numerical simulation and from model propulsion tests) based upon the following reports: BN1 - Raport IMP PAN Nr 147/93, BN7/F and BN7/M - Raport IMP PAN Nr 171/93, BN2 and BN3 - Raport IMP PAN Nr 195/93, BN4 and BN5 - Raport IMP PAN Nr 226/93, BN8/M and BN8/F - Raport IMP PAN Nr 156/93, BN9 - Raport IMP PAN Nr 28/94, BN10 and BN11 - Raport IMP PAN Nr 42/94.
2. Jarzyna H. : « Parametric Analysis of the Effective Mean Velocity Determination by Means of Numerical Simulation » . Raport IMP PAN Nr 57/94, Marine Technology Transactions, vol.5, 1994.
3. Jarzyna H. : « On the Mean Effective Velocity Definition in Model Propulsion Tests ».Raport IMP PAN Nr 27/94, Marine Technology Transactions, vol.5, 1994.
4. Jarzyna H. : « The Relation Between the Mean Effective Velocities from Selected Model Propulsion Tests and from Numerical Simulation Procedures » . Raport IMP PAN Nr 77/94, (to be published in the Transactions of RINA).

NOMENCLATURE

v	-	velocity,
v_V, v_M, v_E		-the mean velocities of an isolated velocity field, respectively : from output, momentum and energy identity,
v_T, v_Q, v_P		-the effective mean velocities, respectively: from thrust, torque and power identity,
K_{TB}, K_{TO}		-the thrust coefficients of the behind screw and the open one, respectively,
K_{QB}, K_{QO}		-the torque coefficients of the behind screw and the open one, respectively,
η_D	-	propulsion efficiency,
η_B, η_O	-	the efficiency of the behind- and the open screw, respectively,
η_H	-	the hull «efficiency»,
η_R	-	relative rotating «efficiency»,
t	-	thrust deduction factor,
SB	-	the behind screw propeller
SO	-	the open screw propeller
FB	-	the behind velocity field
FO	-	the uniform velocity field

T, Q as lower indices - reference to thrust and torque, respectively.