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A method for calculation of the variable forces acting on the screw propeller

SUMMARY

The paper describes a method for calculation of the variable forces acting on the screw propeller.A general approach to the problem and a mathematical model are presented. The method is based on the unsteady lifting surface method. To obtain the results the potential flow theory is used. The geometry of the screw propeller and the velocity field before it can be arbitrary. In the calculations the change of the wake vortex sheet geometry is taken into account.

The method can be used to calculate the thrust force in the condition of ship's motion in waves.

The paper presented at International Conference on Problems of Marine Propulsion HYDRONAV'95, Gdańsk, November 1995

INTRODUCTION

The problem of ship propulsion in waves is not new. To know how the ship behaves in real conditions it is necessary to find the influence of ship's motions on such her parameters as: resistance, velocity, accelerations in different points of hull, roll period etc. All these values are very important from many points of view.

To know the motions a ship makes in waves it is necessary to determine all forces acting on the ship. One of the most important forces is the thrust of the screw propeller.It can be determined in two ways: experimental and theoretical. The experimental methods were the first. The biggest disadvantage of experiment is its high cost. In order to investigate the work of ship propulsion in waves it is necessary to carry out many experiments at different ship velocities, wave lengths and periods. The results of towing tank tests are valid only for the tested ship and to obtain more objective results it is necessary to carry out experiments for a ship series.

More convenient are the theoretical methods. There are two general approaches to the problem. The first is based on the modification of existing propulsion characteristics for calm water. In these methods the work of the screw propeller in waves is assumed the same as in calm water but only the kinematic conditions (velocities) are different. By using the methods, the general propulsion characteristics can be obtained only for a typical screw propeller. The second one gives more detail information. It is based on the vortex theory.An adequate method for solving the problem is the unsteady lifting surface method. It makes possible to calculate velocities and pressures around the screw as well as the forces and moments acting on the screw blades. All the calculations can be carried out also during designing a screw propeller.

The below described method belongs to the unsteady lifting surface methods.

ASSUMPTIONS OF THE METHOD

All further considerations were carried out with the following assumptions:

- the screw propeller is in an arbitrary variable motion, the variation of its angular speed is also possible,
- the screw propeller moves in the ideal fluid, the flow is potential in the fluid domain, excluding the vortex lines representing the screw geometry and their wakes,
- the screw geometry, which can be assumed arbitrary, is constant and exactly known, in particular the radial distribution of pitch angle, length of chord, the maximum thickness and camber of profile, skew-back and rake are known. The screw profile geometry is given by the coordinates of suction and pressure sides of the blade,
- the geometry of free vortex wake, not known a priori, is determined during the calculations,
- in the calculations the full, real three-dimensional velocity field in the screw propeller disk is used. The velocity field is given by the coordinates of three-dimensional vectors in arbitrary points. The ship velocity and the angular speed of the screw propeller are also known.
- the flow around the screw propeller is determined by applying the unsteady lifting surface method based on the potential flow theory. In this method the real screw propeller is replaced by a vortex lattice. The thickness of a screw profile is represented by the source lines, placed in the positions of the vortex lines.
- the calculations are carried out step by step in the time domain.

COORDINATE SYSTEMS

All calculations were carried out in the following systems of coordinates:

- the movable, Cartesian, right handed coordinate system *Oxyz*. The *x*-axis of it has the same direction as the propeller shaft and the positive sense downstream. In the calm water condition the *y*-axis is directed vertically upwards (Fig. 1),
- the local, Cartesian coordinate system $O_l xrt$. Its *x*-axis is parallel to the *x*-axis of *Oxyz* system and *r*- axis is identical with the direction of the screw radius (Fig. 1).

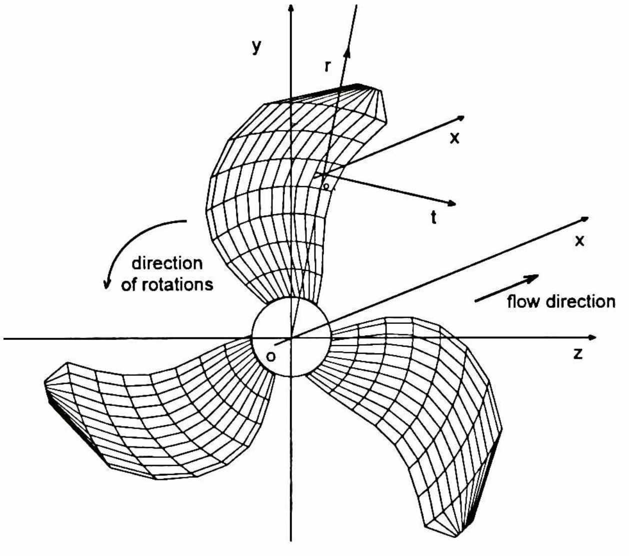

Fig. 1. The systems of coordinates

The motion of the *Oxyz* system describes the global motion of the screw propeller, connected with ship's motion. During the motion the coordinates of any point on the screw in the *Oxyz* system are not changed. The angular motion causes the change of *y* and *z* coordinates of each point.

SCREW PROPELLER GEOMETRY

In the calculation method it is necessary to transform the standard data describing the screw geometry into a set of points with the *x,y,z* coordinates. These points are the endpoints of vortex lines. There are *lpd* points on each chord and *lp* chords on each blade.The *x,y,z* coordinates of lattice points can be obtained by using the following formulas:

$$
\begin{aligned}
wx(i,k,l) &= a_2 \sin[p(i,k)] - su(i,k,l)\cos[p(i,k)] + e(i,k) \\
wy(i,k,l) &= r(i,k)\cos(a_3) \\
wz(i,k,l) &= r(i,k)\sin(a_3) \\
a_1 &= a_2\cos[p(i,k)] + su(i,k,l)\sin[p(i,k)] \\
a_2 &= s(i,k) - 0.5f(i,k) + x_p(i,k,l) \\
a_3 &= a_1 / r(i,k) \quad i=0...ls \quad k=0...lp \quad l=0...lpd
\end{aligned}
\tag{1}
$$

On the basis of these points two sets of vectors $\overline{B}$ and $\overline{T}$ representing bound and free vortexes respectively, can be determined. The coordinates of the vectors are calculated using the above determined coordinates of points:

$$
\begin{aligned}
bx(i,k,l) &= wx(i,k+1,l) - wx(i,k,l) \\
by(i,k,l) &= wy(i,k+1,l) - wy(i,k,l) \\
bz(i,k,l) &= wz(i,k+1,l) - wz(i,k,l) \\
tx(i,k,l) &= wx(i,k,l) - wx(i,k,l+1) \\
ty(i,k,l) &= wy(i,k,l) - wy(i,k,l+1) \\
tz(i,k,l) &= wz(i,k,l) - wz(i,k,l+1)
\end{aligned}
\tag{2}
$$

On the basis of the coordinates of the vectors the coordinates of their midpoints are determined. The coordinates of the centres *C(x,y,z)* of each quadrangle formed by each two bound vectors *b* and two free vortexes *t* are also determined. Then the coordinates of the vectors normal to the surface of each quadrangle are found. The vectors begin in the centre *C* of each quadrangle. Then the coordinates of the tangential vectors are determined. The directions of the tangential vectors are the same as the directions of the profile chords. When these operations are done the vortex lattice on the screw blades is obtained.

WAKE VORTEX SHEET GEOMETRY

In order to determine the forces on the screw propeller it is necessary to model the wake vortex sheet. The sheet contains free vortexes springing from the screw blades.

In the case of a screw propeller in motion the geometry of wake vortex sheet could not be constant in time. Therefore it is necessary to modify the geometry according to the screw propeller's velocities and its displacement variations. In order to do this the points on the trailing edge of each blade are assumed the first points of the wake vortex sheet. The coordinates of the points are modified in each time step according to the following formulas:

$$
\begin{aligned}
wxsz(i,k,j+1) &= wxsz(i,k,j) + vxsz(i,k)dt \\
wysz(i,k,j+1) &= wysz(i,k,j) + vysz(i,k)dt \\
wzsz(i,k,j+1) &= wzsz(i,k,j) + vzsz(i,k)dt \\
& j=0...ko
\end{aligned}
\tag{3}
$$

In this way the first point becomes the second, the second becomes the third etc.The pitch angle of free vortex sheet depends on the velocity $V_{xsz}(i,k)$. The velocity is determined first of all on the basis of the weighted average of the inflow velocity to each point of the blade trailing edge. The strength of each vortex shed is used to determine the weight. It means the greater the strength of the vortex shed the greater its influence on the average value, as the pitch angle of wake vortex sheet is almost the same as the pitch angle of the sheds with great strength. The method makes it possible to account for the induced velocities although it does not take under consideration the wake vortex sheet deformations.

Because the coordinates of points of the wake vortex sheet in each time step have to be changed, the coordinates of the vectors representing sections of free vortex lines are calculated for each calculation angle. This can be done by using the formulas similar to the formulas (2). The shape of wake vortex sheet is exemlified in Fig. 2.

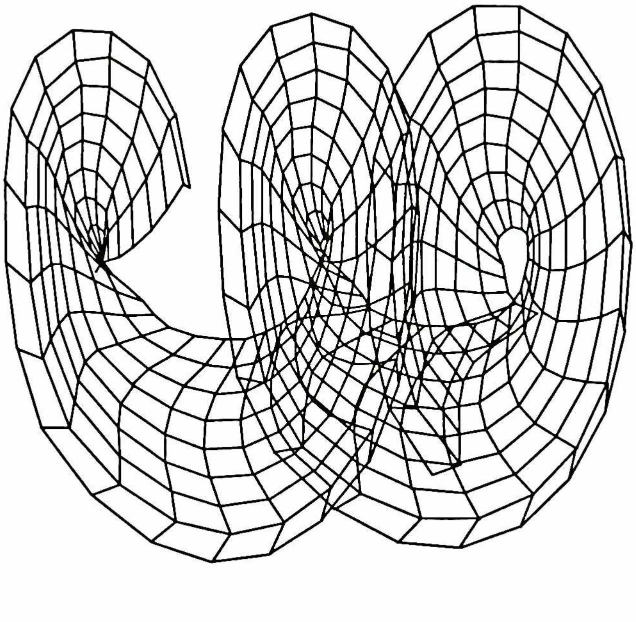

Fig. 2. The wake vortex sheet geometry

BOUNDARY CONDITION

To obtain the velocity induced by the bound and free vortexes and the wake vortex sheet the strength of the bound vortexes have to be known. It can be done by using a boundary condition on the blade surface when assuming the total normal velocity of flow equal to zero on the blade surface i.e.:

$$\overline{V}_n = 0 \tag{4}$$

The components of normal velocity can be easily obtained by multiplying components of velocity vectors by the components of normal vectors in each point.

The total velocity in an arbitrary point contains the following velocities:

- the inflow velocity $\overline{V}_Z$,
- the velocity induced by the bound vortex system $\overline{V}_I$,
- the velocity induced by the wake vortex sheet $\overline{V}_S$,
- velocity induced by the line sources system, modelling the blade thickness $\overline{V}_Q$.

When signing the normal components of the above specified velocities by the index *n*, the boundary condition can be written as follows:

$$V_{Zn}+V_{In}+V_{Sn}+V_{Qn}=0 \tag{5}$$

Setting the boundary condition for each control point *C* the system of the following equations is obtained:

$$\mathbf{V}_{Zn}+\mathbf{V}_{In}+\mathbf{V}_{Sn}+\mathbf{V}_{Qn}=0 \tag{6}$$

The unknown values in the system of equations are the strengths of bound vortexes.

The system of equations is solved in two different ways. During the first calculation cycle the inflow velocities $\overline{V}_Z$ and the velocities induced by the source system $\overline{V}_Q$ are assumed known. In this cycle the circumferential average values of the inflow velocities $\overline{V}_Z$ are used. The velocities are taken from input data. The velocities $\overline{V}_Q$ are calculated separately on the basis of the velocity field and the screw geometry. When assuming the circumferential homogeneity of the velocity field it is possible to express the strength of the free vortex by the strength of the bound vortexes. In result the following system of equations can be written:

$$\mathbf{V}_{In}+\mathbf{V}_{Sn}=\mathbf{V}_{Zn}+\mathbf{V}_{Qn} \tag{7}$$

Having solved the system the strength of bound vortex for the circumferentially homogeneous velocity field is obtained, as well as the strength of the free vortexes in the wake vortex sheet. The strength of the wake vortex sheet calculated earlier and the velocities induced by the wake vortex sheet are used in the next cycles. Therefore only the velocities $\overline{V}_I$ induced by the bound vortex system are unknown in the system of equations (7). The system is derived as follows:

$$\mathbf{V}_{In}=\mathbf{V}_{Zn}+\mathbf{V}_{Qn}+\mathbf{V}_{Sn} \tag{8}$$

The solution of the system makes it possible to determine all the velocities around the blades of the screw and also the forces and moments acting on it. As the number of control points is lower than the number of the bound vortexes, the system of equations is not complete. To solve the problem it is necessary to use the Kutta condition. The condition assumes the circulation on the trailing edge equal to zero. Due to this the strength of the last vortex can be expressed by the strength of other vortexes and in this way the number of unknowns decreased by one.

After this operation the system of equations is complete and can be solved by using one of the relevant mathematical methods. In order to do this the system of equations is transformed into the following form:

$$\boldsymbol{W\Gamma} = \boldsymbol{D} \tag{9}$$

In the presented method the Gausian method is used to solve the system of equations .

VELOCITIES INDUCED BY THE VORTEX AND SOURCES

To set the above described system it is necessary to determine the velocities induced by the vortex and sources modelling the screw blades.

Using the Biot-Savart rule the velocities induced by the system of the vortex lines can be calculated:

$$\overline{V} = \frac{\gamma}{4\pi}\cdot\frac{\overline{B}\times\overline{L}}{L^3} \tag{10}$$

In the *Oxyz* system of coordinates the components of velocity in the control point, induced by the bound vortex $\overline{B}$ *(ii,m,n)* can be expressed by the following formulas:

$$V_x(i,k,l,ii,m,n) = k[by(ii,m,n)lz - bz(ii,m,n)ly]\frac{\gamma(ii,m,n)}{4\pi l^3}$$

$$V_y(i,k,l,ii,m,n) = k[bz(ii,m,n)lx - bx(ii,m,n)lz]\frac{\gamma(ii,m,n)}{4\pi l^3}$$

$$V_z(i,k,l,ii,m,n) = k[bx(ii,m,n)ly - by(ii,m,n)lx]\frac{\gamma(ii,m,n)}{4\pi l^3} \tag{11}$$

where:

$$lx = cx(i,k,l) - bsx(ii,m,n)$$

$$ly = cy(i,k,l) - bsy(ii,m,n)$$

$$lz = cz(i,k,l) - bsz(ii,m,n)$$

The factor *k* takes into account the influence of the distance from the control point to the vortex line. The value of the factor *k* is usually greater or smaller than one.

The velocities induced by the free vortexes $\overline{T}$ are calculated on the basis of the same formulas as the velocities induced by the bound vortex, but the strength γ_T of the vortex $\overline{T}$ *(ii,m,n)* is expressed by the following formulae:

$$\gamma_T(ii,m,n) = \sum_{nn=0}^{n}\left[\gamma(ii,m,nn) - \gamma(ii,m-1,nn)\right] \tag{12}$$

It can be said that the strength of the free vortex γ_T is the sum of the differences of the strength γ of the bound vortexes $\overline{B}$ which are placed below and above this vortex. This sum is taken from the leading edge (*mm*=0) to the displacement of the free vortex $\overline{T}$ *(ii,m,n)* (*nn=m*). The formulas (11) and (12) are used to set the system of equations (8). Each row of the system is the sum of the normal components of the velocities induced by all of the vortexes in a given control point.In result, the number of rows is equal to the number of control points.

The velocities induced by the wake vortex sheet are determined by the same formulas as applied to the bound vortex. Only the first calculation cycle is different. In this cycle the formulas for the free vortexes are used because the strength of the vortex shed is expressed by the strength of the bound vortex according to formulae (12). In this case the summation is carried out from 0 to *lpd*, along the whole chord length.

The sources modelling the thickness of the screw blade also induce velocities. The velocity generated by the source can be calculated by using the following formula:

$$V_Q = \frac{Q}{4\pi L^2} \tag{13}$$

In the *Oxyz* system of coordinates the components of velocity in the control points *C(i,k,l)*, induced by the source *Q(ii,m,n)*, are as follows:

$$V_{Qx}(i,k,l,ii,m,n) = k\frac{Q(ii,m,n)lx}{4\pi l^2}$$
$$V_{Qy}(i,k,l,ii,m,n) = k\frac{Q(ii,m,n)ly}{4\pi l^2} \tag{14}$$
$$V_{Qz}(i,k,l,ii,m,n) = k\frac{Q(ii,m,n)lz}{4\pi l^2}$$

As the formula (13) is valid only for the point source the factor k which corrects the velocity V_Q has to be used.

The intensity of source Q is determined by assuming the intensity balancing the inflow of water to the appropriate volume of the blade. The inflow of water to the blade can be caused by two reasons. The first is the change of volume of the blade on the same stream line. The second is the difference between the inflow velocities for each element of the blade. An assumption was made that the change of inflow velocity is very small and can be neglected while calculating the intensity of source. The velocities induced by the source lines are much smaller than the velocities induced by the vortex lines and therefore those velocities less influence the total results of the calculations. For the purpose of this calculation the intensity of the sources was calculated only once. The calculations are carried out on the basis of the circumferentially homogeneous velocity field and without taking into account the velocities induced by the vortex lines. Due to this the intensity of source *Q(ii,m,n)* can be calculated by using the following formula:

$$Q(ii,m,n) = (S_1 - S_2)\sqrt{V_{Zx}^2(ii,m,n) + [\omega r(ii,m,n)]^2} \tag{15}$$

where:

$S_1 - S_2$ - the difference between the fore and after surface of the volume element.

The intensity of the sources and the velocities induced by the sources are determined only once during the first calculation cycle. In the next cycles they are taken as the known values in the boundary condition.

DETERMINATION OF FORCES AND MOMENTS

After the determination of the velocities induced by the vortex and the source lines and after solving the system of equations (9) it is possible to obtain the forces and moments acting on the screw blades. The velocities induced by the vortex lines can be obtained by multiplying the matrix W by the matrix-vector Γ. The result of this calculation is the velocity field around the screw. If the velocity field is known the Bernoulli's equation can be used. The equation for the screw blades has the following form:

$$\frac{p_0}{\rho} + \frac{V_0^2}{2} = \frac{p}{\rho} + \frac{V^2}{2} - \frac{(r\omega)^2}{2} - \frac{\partial \Phi}{\partial t} \tag{16}$$

The formulae (16) can be transformed into the form which enables to determine the pressure coefficient:

$$c_p = \frac{p_0 - p}{\frac{1}{2}\rho\left[V_0^2 + (r\omega)^2\right]} = \frac{V^2 - V_0^2 - (r\omega)^2}{V_0^2 + (r\omega)^2} - \frac{1}{V_0^2 + (r\omega)^2}\frac{\partial \Phi}{\partial t} \tag{17}$$

The velocity V in the $O_r xrt$ system of coordinates has the following components:

V_x - in the x - axis direction,
V_r - radial,
V_T - tangential.

The components contain all the velocities which are present in the flow:

the inflow velocity V_Z,
the velocities V_l and V_Q induced by the vortex and source lines,
the velocities V_S induced by the wake vortex sheet.

The velocity V is not the same on both sides of the blade. The difference between the pressure side and the suction side velocities is equal to the strength of the circulation γ_p at each considered point.

Assuming the strength does not cause any radial components of velocity and one half of the strength causes an increment of the velocity on the suction side and the other half that on the pressure side, the increment of velocity at the control point *C(i,k,l)* can be expressed as follows:

$$V_{Ct} = \frac{\gamma_p(i,k,l)nx(i,k,l)}{2\sqrt{nt(i,k,l)^2 + nx(i,k,l)^2}} \tag{18}$$

$$V_{Cx} = -\frac{\gamma_p(i,k,l)nt(i,k,l)}{nx(i,k,l)} \tag{19}$$

Taking into consideration the formulas (18) and (19) the pressure coefficients for the suction and pressure sides of the blade can be expressed as follows:

$$c_{ps,p}(i,k,l) = \frac{\partial \Phi}{\partial t}\frac{1}{V_0^2 + [r(i,k,l)\omega]^2} +$$
$$+\frac{[V_{Zx}(i,k,l) + V_{lx}(i,k,l) + V_{Sx}(i,k,l) \pm V_{Cx}]^2}{V_0^2 + [r(i,k,l)\omega]^2} +$$
$$+\frac{[V_{Zt}(i,k,l) + V_{lt}(i,k,l) + V_{St}(i,k,l) \pm V_{Ct}]^2}{V_0^2 + [r(i,k,l)\omega]^2} +$$
$$+\frac{[V_{Zr}(i,k,l) + V_{lr}(i,k,l) + V_{Sr}(i,k,l)]^2 - V_0^2 - (r\omega)^2}{V_0^2 + [r(i,k,l)\omega]^2} \tag{20}$$

The pressure coefficients are used to calculate the forces and moments acting on the screw blades. The components of the forces and moments generated on the element of the screw blade, which belongs to the control point *C(i,k,l)*, are calculated on the basis of the following formulas:

$$F_x(i,k,l) = \frac{1}{2}\rho p(i,k,l)\{V_0^2 + [r(i,k,l)\omega]^2\}\{[c_{ps}(i,k,l) +$$
$$-c_{pp}(i,k,l)]nx(i,k,l) + cd \cdot wtx(i,k,l)\}$$

$$F_y(i,k,l) = \frac{1}{2}\rho p(i,k,l)\{V_0^2 + [r(i,k,l)\omega]^2\}\{[c_{ps}(i,k,l) +$$
$$-c_{pp}(i,k,l)]ny(i,k,l) + cd \cdot wty(i,k,l)\}$$

$$F_z(i,k,l)=\frac{1}{2}\rho p(i,k,l)\{V_0^2+[r(i,k,l)\omega]^2\}\{[c_{ps}(i,k,l)+ -c_{pp}(i,k,l)]nz(i,k,l)+cd\cdot wtz(i,k,l)\}$$

$$M_x(i,k,l)=\frac{1}{2}\rho p(i,k,l)\{V_0^2+[r(i,k,l)\omega]^2\}\{[c_{ps}(i,k,l)+ -c_{pp}(i,k,l)][nz(i,k,l)cy(i,k,l)-ny(i,k,l)cz(i,k,l)]+ +cd[wtz(i,k,l)cy(i,k,l)-wtz(i,k,l)cz(i,k,l)]\}$$

$$M_y(i,k,l)=\frac{1}{2}\rho p(i,k,l)\{V_0^2+[r(i,k,l)\omega]^2\}\{[c_{ps}(i,k,l)+ -c_{pp}(i,k,l)][nx(i,k,l)cz(i,k,l)-nz(i,k,l)cx(i,k,l)]+ +cd[wtx(i,k,l)cz(i,k,l)-wtz(i,k,l)cx(i,k,l)]\}$$

$$M_z(i,k,l)=\frac{1}{2}\rho p(i,k,l)\{V_0^2+[r(i,k,l)\omega]^2\}\{[c_{ps}(i,k,l)+ -c_{pp}(i,k,l)][ny(i,k,l)cx(i,k,l)-nx(i,k,l)cy(i,k,l)]+ +cd[wty(i,k,l)cx(i,k,l)-wtx(i,k,l)cy(i,k,l)]\}$$

In order to obtain the total forces and moments it is necessary to integrate the partial forces over the whole screw surface.

CONCLUSIONS

The presented mathematical model enables to calculate the forces and moments generated on the screw propeller working in an arbitrary velocity field. The most important characteristic features of the method are:

- The geometry of the screw propeller can be arbitrary, without any limitations.
- The arbitrary three-dimensional velocity field before the screw propeller can be applied.
- The motion can be arbitrary, not only rectilinear.
- The forces acting on each screw blade are calculated simultaneously.
- The changes of shape of the wake vortex sheet are accounted for in the calculations.
- The calculation is carried out in the time domain.

The method was transformed to a computer program. It was compiled and prepared to work under MS-DOS, IRIX (5.2 and 6.0) and Linux computer operation systems.

NOMENCLATURE

$\overline{B}$	- vector of the vortex line section,
$bx(i,k,l)$, $by(i,k,l)$, $bz(i,k,l)$	- coordinates of the vector $\overline{B}$
$bsx(ii,m,n)$, $bsy(ii,m,n)$, $bsz(ii,m,n)$	- coordinates of the midpoint of the vector $\overline{B}(ii,m,n)$
$cx(i,k,l)$, $cy(i,k,l)$, $cz(i,k,l)$	- coordinates of the control point C
cd	- drag coefficient of the blade profile
c_p	- pressure coefficient
c_{pp}	- pressure coefficient for the pressure side of the blade
c_{ps}	- pressure coefficient for the suction side of the blade
dt	- time step
$e(i,k)$	- rake
$f(i,k)$	- length of profile chord
$F_x(i,k,l)$, $F_y(i,k,l)$, $F_z(i,k,l)$	- components of the forces generated on the element of the screw blade
k	- correction factor
ko	- number of elements of the wake vortex sheet
l	- length of vector, $\sqrt{lx^2+ly^2+lz^2}$
$\overline{L}$	- vector connecting the vortex line with the control point
L	- length of the vector connecting the source with the control point
lp	- number of screw blade profiles
lpd	- number of points profile
ls	- number of screw propeller blades
$M_x(i,k,l)$, $M_y(i,k,l)$, $M_z(i,k,l)$	- components of the moments generated on the element of the screw blade
$nx(i,k,l)$	- component of the vector normal to the surface of blade, in the x - axis direction
$nt(i,k,l)$	- component of the vector normal to the surface of blade, in the t - axis direction
p	- pressure on the screw blade
p_0	- pressure before the screw
$p(i,k)$	- pitch angle
$p(i,k,l)$	- area of the blade element
Q	- source intensity
r	- radius of the screw blade profile
$r(i,k)$	- radius of k-th profile
$s(i,k)$	- skew-back
$su(i,k)$	- maximum profile camber
$tx(i,k,l)$, $ty(i,k,l)$, $tz(i,k,l)$	- coordinates of the vector T
V	- resultant velocity on the screw blade
$\overline{V}$	- vector of induced velocity
V_{Ct}	- tangential component of velocity increment at the control point
V_{Cx}	- axial component of velocity increment at the control point
V_0	- velocity of water before the screw
$\mathbf{V}_{In}$	- matrix vector of velocities induced by the bound vortexes
$\mathbf{V}_{Sn}$	- matrix vector of velocities induced by the wake vortex sheet
V_Q	- velocity induced by the source
$\mathbf{V}_{Qn}$	- matrix vector of velocities induced by the sources
$V_{Qx}(i,k,l,ii,m,n)$, $V_{Qy}(i,k,l,ii,m,n)$, $V_{Qz}(i,k,l,ii,m,n)$	- components of the velocity induced at the control point (i,k,l) by the source (ii,m,n)
$V_x(i,k,l,ii,m,n)$, $V_y(i,k,l,ii,m,n)$, $V_z(i,k,l,ii,m,n)$	- components of the velocity induced at the control point (i,k,l) by the vortex (ii,m,n)
$V_{Zx}(ii,m,n)$	- axial component of the inflow velocity at the radius $r(ii,m,n)$
$vxsz(i,k)$, $vysz(i,k)$, $vzsz(i,k)$	- component velocities of the screw propeller

$wtx(i,k,l)$
$wty(i,k,l)$ - components of the vector tangent to the blade surface, at the point $C(i,k,l)$
$wtz(i,k,l)$

$wx(i,k,j)$
$wy(i,k,j)$ - coordinates of the lattice points
$wz(i,k,j)$

$wxsz(i,k,j)$
$wysz(i,k,j)$ - coordinates of the wake vortex sheet points
$wzsz(i,k,j)$

$x(i,k,l)$ - distance of the point (k,l) from the leading edge

γ - strength of the vortex line

$\gamma\ (ii,m,n)$ - strength of the vortex $\overline{B}\ (ii,m,n)$

γ_T - strength of free vortex

ρ - density of water

ω - angular velocity of the screw

Φ - velocity potential

BIBLIOGRAPHY

1. Basin A. M., Miniowicz I. J.: „Teoria i rasczet grebnych wintow". Sudpromgis, 1963.(in Russian)
2. Dudziak J.: „ Ship Theory". Gdańsk, 1988.(in Polish)
3. Krężelewski M.: „ Ship Hydromechanics". Gdańsk, 1982. (in Polish)
4. Prosnak W. J.: „ Fluid Mechanics". Warszawa, 1970. (in Polish)
5. Szantyr J.: „A New Method for the Analysis of Unsteady Propeller Cavitation and Hull Surface Pressures". RINA Spring Meetings. London, 1984
6. Wang G.-Q., Xu L.-X., Yang C.-J., Tamashima M., Ogura M.: „ Unsteady Nonlinear Vortex Lattice Method for Prediction of Propeller Performances". Proceedings of Nineteenth Symposium on Naval Hydrodynamics, Seoul, 1992

Appraised by Henryk Jarzyna, Prof.,D.Sc.,N.A.

Miscellanea

Seaway traffic engineering

There is a special group among the scientists dealing with shipping technical problems, who investigate the relationships of the ship operation parameters (ship main dimensions, manoeuvrability, draft, propulsive power etc) and the parameters of port water regions (basin dimensions, depth, conditions of ship navigation). The research area called generally „ seaway traffic engineering " is developed in Poland by the Maritime Navigation Institute, Maritime University of Szczecin, headed by prof. Stanisław Gucma, sea captain.

The Institute with its computerized ship manoeuvring simulator is claimed to be one of the best equipped in Europe. The possibilities are broadly used to:

- determine limitations imposed on the ships which can safely enter and manoeuvre within a given port
- elaborate foredesigns of construction or reconstruction of waterways and port basins to handle a given group of ships there
- carry out systematically, with the use of its simulator, courses of ship handling in the restricted waters (ports, water lanes, turning basins).

The Institute has at its disposal many simulation software systems covering ships of different type and size (bulk carriers, general cargo ships, ferries etc) and models of various ports (e.g. ports of Świnoujście, Gdynia, Dover, Ystad, New York).

This is the Institute where the operation parametres were determined of the POLONIA ferry ship, suitable to enter Ystad, the optimum entrance parametres of the ports of Kołobrzeg and Łeba as well as the extreme parametres of the ships which can safely enter the port of Świnoujście.

The above presented examples well illustrate the broad range of the Institute's research potential suitable for solving many practical problems.

Current *reports*

POLISH ACADEMY OF SCIENCES
INSTITUTE OF FLUID FLOW MACHINERY
GDAŃSK

A computer program for analysis of cavitation and unsteady forces on propellers, based on surface panel method

The Ship Design and Research Centre (CTO) has ordered with the Institute of Fluid Flow Machinery a new computer program for analysis of cavitation, unsteady hydrodynamic forces and induced pressure pulses on conventional and ducted propellers. The program is to be based on the surface panel method, which in the recent years has rapidly gained popularity as the CFD tool for propeller analysis and is gradually superseding the up to now dominant lifting surface theory. Application of the surface panels method enables much more accurate numerical representation of the propeller and consequently, much more reliable prediction of the unsteady pressure field on propeller blades, especially in the crucial vicinity of the leading edge. This is decisive in correct prediction of the unsteady cavitation phenomena and resulting pressure pulsations generated by the propeller in the surrounding space.

The new program will analyze the operation of the ducted or open propeller of known geometry in the known three-dimensional non-uniform velocity field, producing the following information:

- unsteady pressure on the blades and on the duct
- extent of unsteady laminar, bubble and tip vortex cavitation
- time-dependent hydrodynamic forces on the propeller and on the duct
- pressure pulses induced by the cavitating propeller in the prescribed points of space.

This information will play an important role in the process of propeller optimisation at the design stage. It is expected that the new program will improve the accuracy of numerical predictions of cavitation and unsteady forces in comparison with currently used lifting surface programs. Due to a complicated theoretical model the new program will have to be installed on the newly acquired powerful Silicon Graphics Indigo workstations at the Ship Hydrodynamics Laboratory of CTO. According to plan the new program will become operational in July 1996, when the extensive experimental validation will start. The development of the new program is led by Jan Szantyr, Assoc. Prof.