THE INFLUENCE OF INHOMOGENEOUS CURRENT ON THE SHIPS MOTION

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The navigation on restricted waterways like rivers is complicated by the existence of current. Two manoeuvring situations indicate the problems which have to be overcome by the pilots and captains.

- When entering a harbour with still water coming from a river with current (or vice versa) the ship is affected by different current zones which induce a transversal and a turning motion when the ship is partly in a cross-flowing current.
- The turning manoeuver in a river bend with different current velocities on the inner and the outer side of the fairway can be made either very easy using the current to turn the vessel or nearly impossible if carried out in the wrong direction.

Extensive model tests have been carried out in the shallow water basin of the DST to investigate the forces acting on a vessel in inhomogeneous current, which has been reproduced by the current facility and a fictitious harbour entrance made of wooden walls. The forces and moments acting on different vessels placed at varying positions and courses in the inhomogeneous current and the current velocities itself at a dense mesh have been measured.

Dependent on the position and direction of the model in the field, mean values of the longitudinal and transverse current velocities u_C and v_C and the attack point of v_C have been calculated and set into relation to the measured forces X, Y and the moment N. Alternatively other approaches of the consideration of the current have been implemented in the simulation software and investigated.

The introduction of a lateral resistance distribution improves the consideration of current effects and refines the results of the motion calculations. Using the inhomogeneous current in a simulation program the scenarios described above can be reproduced as expected.

1. MODEL TESTS

In the large shallow water towing tank of the DST, which is 200 m long, 10 m wide and has a maximum water depth of 1.25 m a harbour entrance has been built up using wooden walls (see figure 1). The right half of the tank was used to generate a steady current with a flow speed of 0.3 m/s. Using a model scale of 1/40 this equals to a current velocity of 3.7 kn.

The current field was measured in the horizontal plane using an ultrasonic probe with a mesh width of 0.2 m. Figure 1 shows the vector field with the nearly straight flow in the “river”-side and the resulting vortex in the harbour mouth. All velocities are mean values over the data acquisition period of about 30 sec. For that reason only big vortices can be detected and small turbulences created by separation are suppressed.

The forces induced by this current field were measured at a captive model of a container feeder vessel with L = 126 m, B = 21.3 m and T = 7.5 m. The water depth was adjusted to h = 15 m in full scale. The longitudinal force X and the lateral forces Y_f and Y_a were measured leading to the lateral force Y and the yawing moment N by using the levers of the force gauges Y_f and Y_a.

The model was positioned with headings every 15° on a mesh with a width of 20 cm covering the areas of constant flow outside the harbour, inhomogeneous flow in the harbour mouth and in the slow vortex. In total 578 measurements were made for this model.

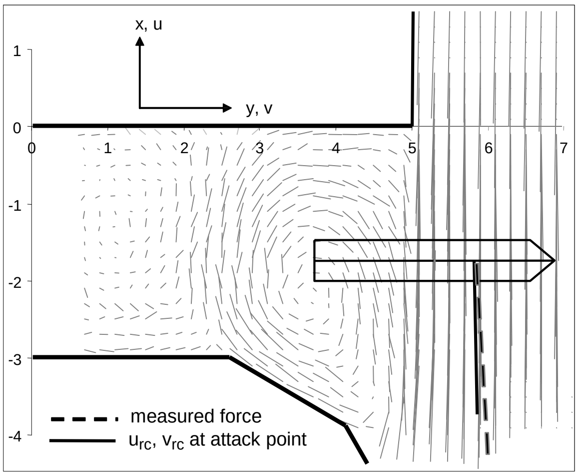

Fig. 1 Harbour setup for the measurement of the forces on a vessel in inhomogeneous current

2. EVALUATION

2.1 Coordinate system and vectors

The general relation between the vessels velocity through the water (w), the current velocity (c) and the ships velocity over ground (g) is given by the vector addition in equation 1.

$$\vec{V}_g = \vec{V}_w + \vec{V}_c \tag{1}$$

Depending on the viewpoint the velocities can be seen in earth fixed absolute coordinate system (a) or the ships own relative system (r). While for the calculation of the hydrodynamic forces the relative system is used the current information and the ships overall motion are given and calculated in absolute coordinates. In each system the velocity vector V in the horizontal plane can be separated into a longitudinal component (u) and a lateral component (v).

Two angles (beside the current direction ψ_C) are used to calculate the ships velocity through the water in absolute and relative components: the course angle ψ and the drift angle β. In figure 2 all the relevant vectors and coordinate systems are shown using the variables and subscripts indicated above.

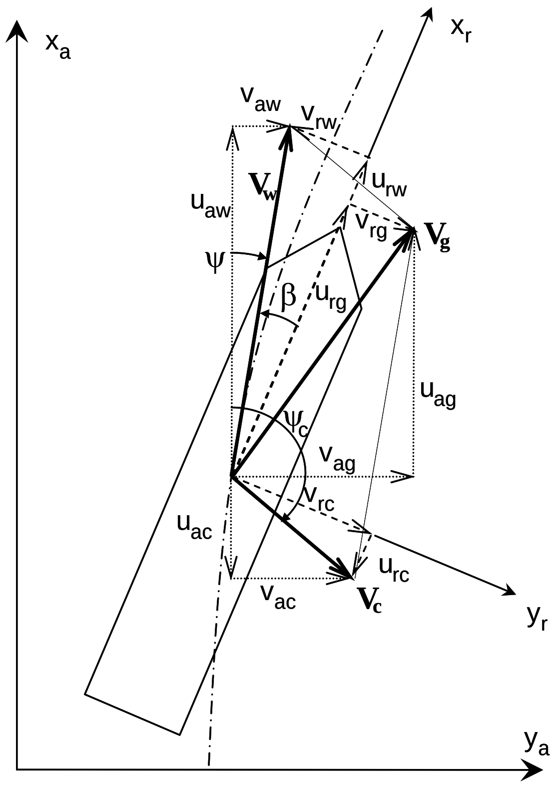

Fig. 2 Vectors and coordinate systems

2.2 Current distribution

For the investigation of the current influence to the forces the inhomogeneous current along the ships axis has to be determined. Dependent on the accuracy of the current information (density of the current field) a sufficient number of control points is distributed between bow and stern of the ship. For each point the mean current velocity is computed in the relative coordinate system using the reciprocal quadratic weight for the distances of the current points in the vicinity of the control point. With this algorithm the distribution of the current field can be calculated. The result for the case in figure 1 is shown in figure 3.

A small longitudinal component u_{rc} can be found, which is from the slow vortex the stern is situated in. This vortex generates also a moderate lateral component while the bow is full in the strong current with high values for the lateral velocity v_{rc}.

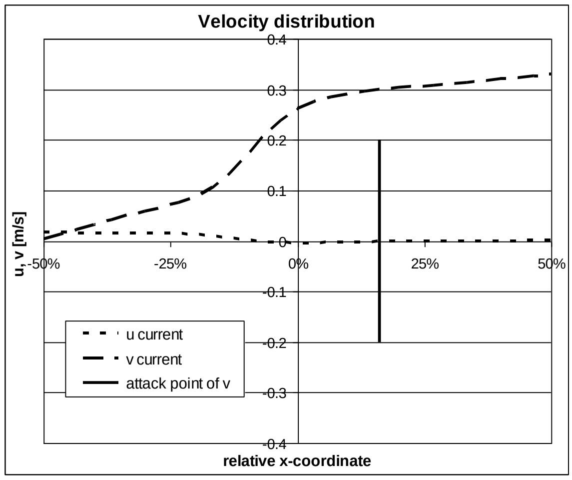

Fig. 3 Current distribution along the ships axis

It has to be said, that there is a fundamental error in this approach which cannot be eliminated: the presence of the ship changes the current which is taken from an undisturbed flow field. Especially on shallow water this can lead to underestimations because the blocking of the flow due to small under keel clearance will increase the flow and the forces induced by it.

The attack point of v_{rc} in figure 3 is calculated in the same manner using levers and moments for the lateral velocity as the calculation of the attack point of a force distribution. The mean values for u_{rc} and v_{rc} are used in the further calculations in the simulation program.

2.2 Lateral resistance distribution

The calculation of the attack point of the lateral force using the levers only does not fully represent the situation of real ships in inhomogeneous current. Especially modern container vessels with protruding bulbous bows and flat rising stern sections are more sensitive to crossing currents in the bow area than at the stern. This can be considered by the introduction of a longitudinal distribution of the lateral resistance.

The points, where the current is calculated, are given by a list which also includes a local lateral resistance factor for each point. This means, the current can also reach the bulbous bow, which is forward of the perpendicular and will result in a significant influence to the attack point and the yawing moment or the rotation of the ship. In figure 4 some examples of fictitious distributions of the lateral resistance are shown.

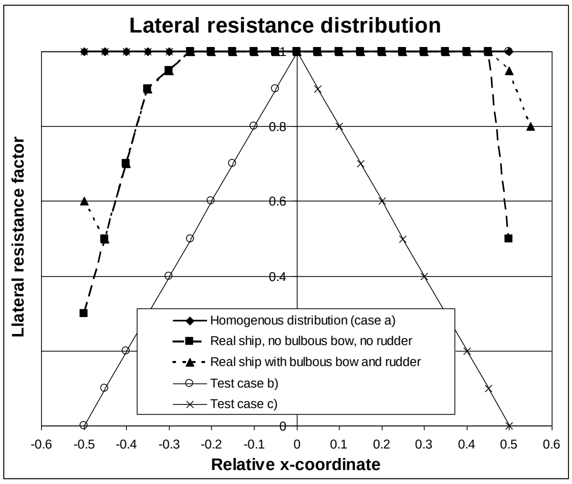

Fig. 4 Different distributions of the lateral resistance

2.3 Forces

The forces and moments measured in the model tests have been nondimensionalized with the dynamic pressure using the current velocity in the undisturbed flow and the lateral area L·T as reference values (see equations 2 and 3).

$$X', Y' = X, Y / (\rho/2 \cdot V_c^2 \cdot L \cdot T) \qquad (2)$$

$$N' = N / (\rho/2 \cdot V_c^2 \cdot L^2 \cdot T) \qquad (3)$$

As an example the lateral force Y' is plotted versus the velocity v_{rc} normalized with the velocity of the flow outside the harbour. The fairing curve is used to model these force for the later application in the simulation software.

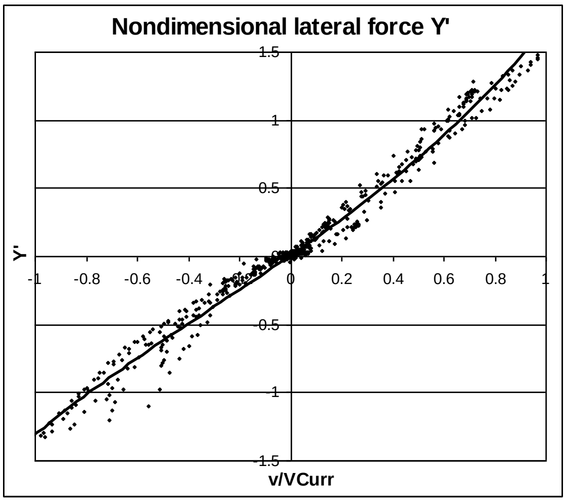

Fig. 5 Force Y' vs. current component v_{rc}/V_{curr}

3. SIMULATIONS

In general the ship is taken with the current and it has only taken into account, how to deal with the accelerations when the current changes. In an inhomogeneous current an additional effect is of central relevancy: The rotation. Several approaches are possible how to treat this aspect and they are explained and compared in the following. Either

- additional forces can be introduced while the current velocity is zero or
- the current components are used in the calculations and no forces are active.

3.1 Rotation from velocity distribution

Using the current distribution along the ships axis a rotation can be calculated. It is used in the further calculations of the ships motion in the mathematical formulation of the motion equations. No additional forces are introduced.

3.2 Rotation from additional yawing moment

The attack point of the lateral current velocities is multiplied with a lateral force calculated by the mean lateral current and the lateral area of the ship. This lever multiplied with the lateral force lead to the yawing moment induced by the inhomogeneous current. No yaw velocity is considered in the calculations.

3.3 All motions from forces

The calculation of additional forces induced by the local current needs the calculation of the relative current in the moving ship coordinate system. Thus only current effects which are changing to the previous situation will be transformed into forces. Based on the measurements of forces (see chapter 2.3) these differential currents are used for the calculation of additional forces and moments.

3.4 Comparison

All three approaches have been implemented in the simulation software and tested with the same manoeuvre (crossing a constant current field). It has been found that only slight differences occur. These are related to the different origin of the yawing motion. While in 3.1 the rotation is calculated directly, in 3.2 it is taken from a yawing moment which is calculated by the lateral force and the attack point and in 3.3 it is created by a formula based on the differential currents.

For the examples in the next chapter the approach with the calculation of the rotation from the current distribution is used.

4. EXAMPLES

4.1 Current fields

Different situations can be imagined, rising in the degree of complication (see figure 6):

- No current – only planar motion
- Homogenous current – only additional translation of the relative to the absolute coordinate systems (α)
- Flow following a river with no lateral change – translation with changing directions (β)
- Real river flow with changing current velocities across the river (γ).

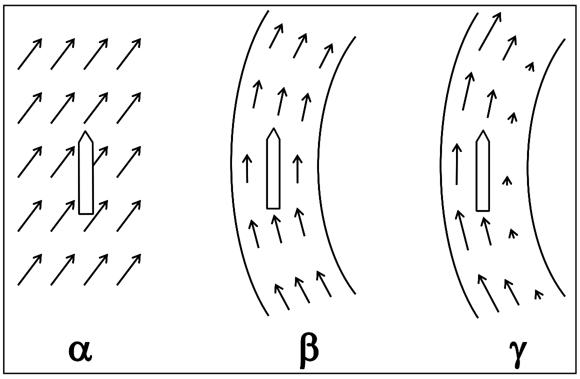

Fig. 6 Different current configurations

Only in case (γ) a real inhomogeneous current exists. The change of velocity across the river can be either constant or following a special profile as indicated in figure 7.

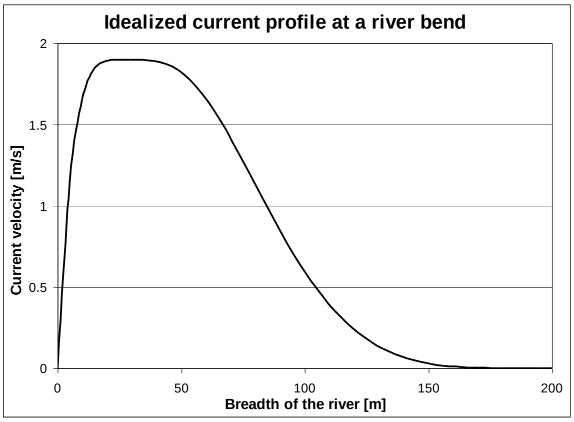

Fig. 7 Hypothetic current profile

4.2 Crossing manoeuvres

A typical manoeuvre with inhomogeneous current is the crossing off a constant flow. This very unrealistic situation is a good scenario for the investigation of the influence of the lateral resistance distribution mentioned in chapter 2.2 . Three theoretical cases (see figure 4) are compared in figure 8 and 9 using the relative x-coordinates -0.5 for the stern of the ship and +0.5 for the bow.

a) Constant lateral resistance between -0.5 and +0.5

b) Flat stern (0 to 1 between -0.5 and 0, then 1)

c) Flat bow (1 until 0, the 1 to 0 from 0 to +0.5)

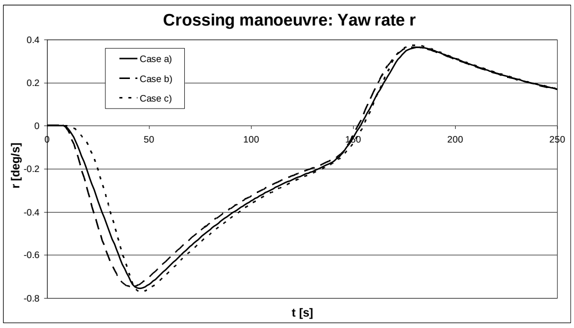

Fig. 8 Yaw rate during crossing manoeuvre with different lateral resistance distributions

It can be observed that for cases a) and c), where the bow enters the current zone from the still water area sharply, there is a sudden increase of the yaw rate, while a smooth increase of the forward lateral area leads to a smooth change of the yaw rate. Likely the smooth stern of case b) leads to an earlier reduction of the yaw rate because the whole hull has entered the constant flow earlier.

In reality this kind of manoeuvre can be observed when entering a harbour coming from a river or vice versa. It always happens that the part of the vessel which is protruding into the current is picked up and a yawing motion is induced.

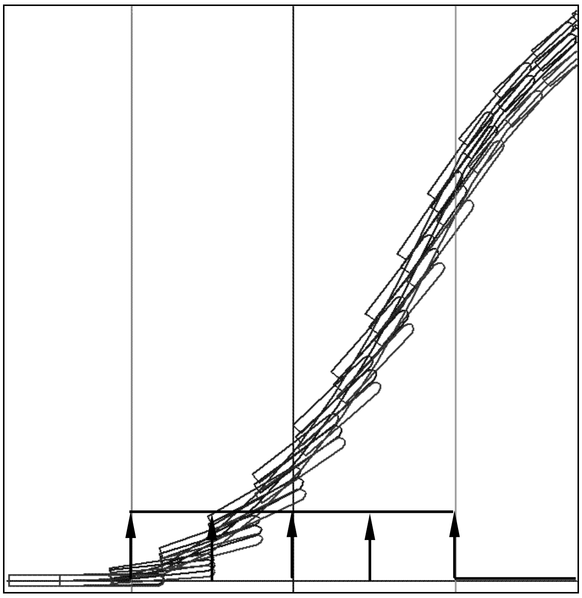

Fig. 9 Path of crossing manoeuvre with different lateral resistance distributions

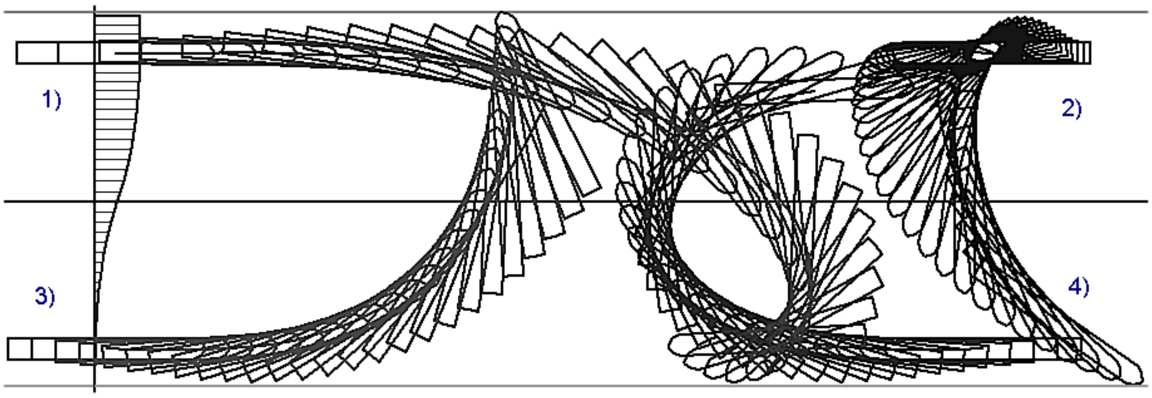

Fig. 10 Turning in inhomogeneous current

4.3 Turning manoeuvres

The next test case is a straight flow with a current profile like it is shown in figure 7. The flow goes to the right, loosing velocity from top to down. The inland vessel is turning with constant rudder angle and starting at a constant distance to the upper / lower wall. Thus 4 different cases can be observed:

1) Going downstream, turning out of the current. At half time the bow enters slower current and the rotation is increased.

2) Going upstream, turning out of the current. Now the stern is in the current, while the bow leaves it. The rotation is reduced and no turning is possible.

3) Coming from still water turning upstream. The current reduces the turning ability and the manoeuvre fails.

4) Coming from still water turning downstream. When the bow enters the current picks it up and supports the rotation.

In figure 10 the tracks of the turning manoeuvres are shown. The starting points are indicated by the numbers of the cases. Track 1 and 3 are longer due to the current, 2 and 4 are shorter for the same reason.

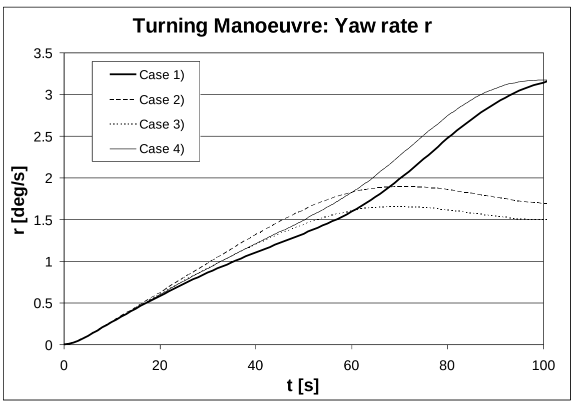

Fig. 11 Yaw rate in turning manoeuvre

More information about the turning effect of the inhomogeneous current can be detected in figure 11, which shows the yaw rate of all four examples. During the first half of the turning manoeuvres the yaw rate is nearly the same for all cases, except, that it is a bit higher for case 2 starting against the current and a bit lower for case 1 starting with the current.

After about 60 sec, when all ships are crossing the centre line of the flow, the current effect on the rotation develops strongly. It either improves the turning ability or worsens it and makes the turning manoeuvre possible within the width of the river or not.

4.4 Current in a river

In order to simulate the motion of inland waterway ships on a river realistically, a suitable current field has to be provides. This can either result from real measurements of e.g. hydrographic institutes or by 2-dimensional CFD calculation of that river.

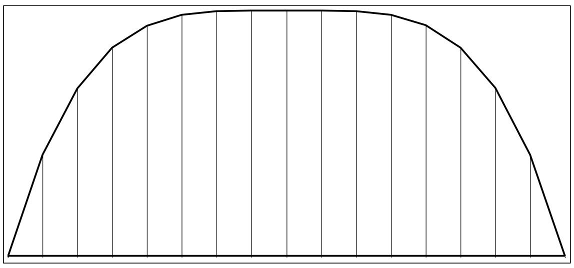

Fig. 12 Current profile for the straight river

Another suitable method is the estimation of the currents just by the mean flow velocity and the river boundaries. At first a suitable current profile regarding the boundaries has to be created. An example for this is given in figure 12.

This profile is used to calculate the mass flow through a section. In a bend the profile is distorted with a certain eccentricity depending on the direction of the bend and the radius of the curve (see figure 7). After that the mass flow is used to scale the velocities of the distorted curve which results in an increasing maximum velocity with the curve radius. The final result is shown in figure 13.

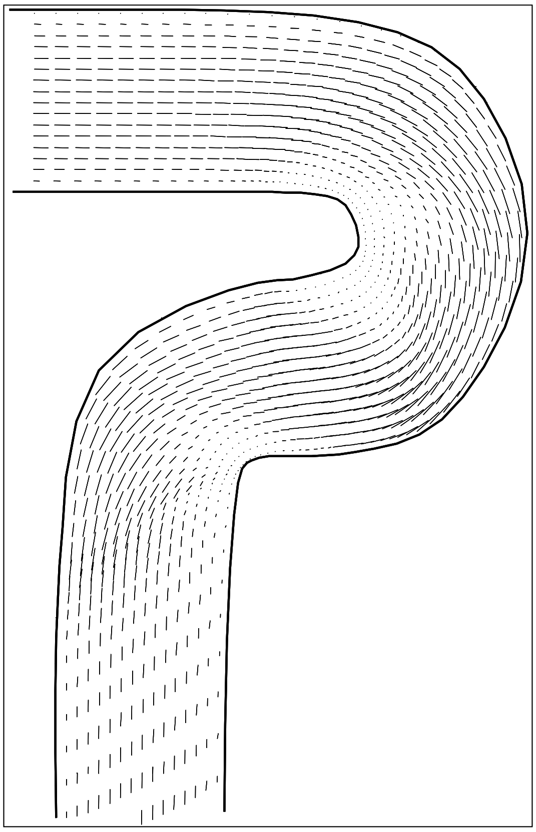

Fig. 13 River current using profiles

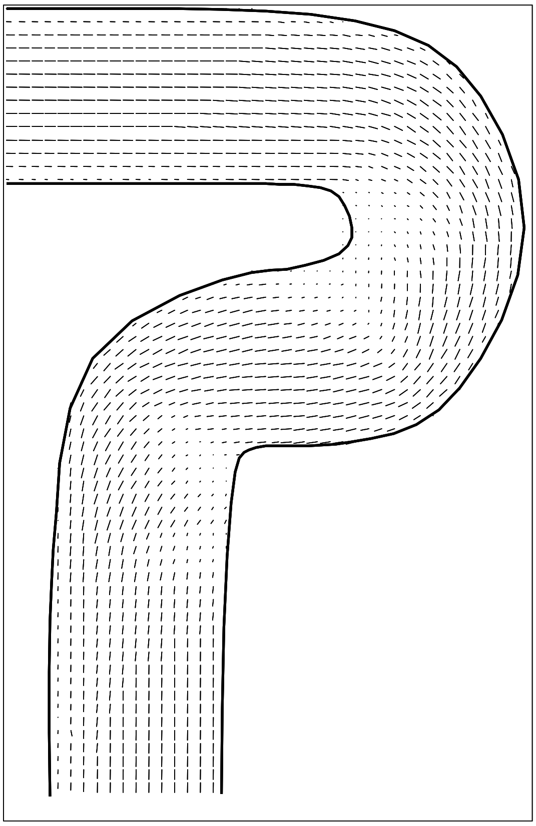

Fig. 14 River current using a mesh

The fictitious river is describes by 2 curves with an equal number of control points. Between each pair of points a profile is calculated using the tangents at both points for the direction, the mean value of the curvature for the eccentricity of the profile and the mass flow for the scaling of the vectors. In figure 13 the profiles can clearly be seen – the control points of the outer curve are always ahead of the inner ones to generate a more natural current distribution. This helps to calculate a realistic meandering flow with high velocities on the outer lane and relative still water at the inner side of the bend.

An alternative and more even distribution of the current can be done by transforming it onto a mesh with constant width as it is given in figure 14. This might be preferable for the simulation process if the quality of the result is dependent on the number of vectors in vicinity of the ship.

5. CONCLUSIONS

- While a homogeneous current affects only the translation of a vessel the inhomogeneity alone causes the rotation of the ship.

- The current effects can either be calculated using the current itself, the forces due to the current or combinations of both.

- Improvements to the calculation of the rotation can be made by the introduction of a lateral resistance distribution.

- Using a simulation environment with realistic current vectors and an advanced consideration of the current in the software all effects observed in reality can be reproduced on a simulator correctly.

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