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Editorial

POLISH MARITIME RESEARCH is a scientific journal of worldwide circulation. The journal appears as a quarterly four times a year. The first issue of it was published in September 1994. Its main aim is to present original, innovative scientific ideas and Research & Development achievements in the field of :

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which could find applications in the broad domain of maritime economy. Hence there are published papers which concern methods of the designing, manufacturing and operating processes of such technical objects and devices as : ships, port equipment, ocean engineering units, underwater vehicles and equipment as well as harbour facilities, with accounting for marine environment protection.

The Editors of POLISH MARITIME RESEARCH make also efforts to present problems dealing with education of engineers and scientific and teaching personnel. As a rule, the basic papers are supplemented by information on conferences , important scientific events as well as cooperation in carrying out international scientific research projects.

Scientific Board

Comparative analysis of selected design variants of propulsion system for an inland waterways ship

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ABSTRACT

In this paper are presented design assumptions and technical conditions as well as selected design versions of propulsion system for an inland waterways ship, and also a preliminary comparative analysis of two solutions. In the first version this is a combustion-electric system fitted with frequency converter and in the other – combustion-hydraulic one with hydrostatic reduction gear.

Keywords : ship propulsion systems, combustion-electric driving system, combustion-hydraulic driving system

INTRODUCTION

Today several kinds of propulsion systems are applied on board inland waterways ships, out of which the following can be enumerated :

❖ conventional one fitted with a combustion engine, toothed gear and fixed or controllable pitch propeller, free or ducted in a fixed or pivotable Kort's nozzle

❖ combustion-electric one fitted with an electric transmission and frequency converter making it possible to steplessly control rotational speed of the propeller which may be fixed one

❖ combustion-hydraulic one fitted with a hydrostatic transmission and fixed propeller

❖ propulsion system fitted with two azimuthal propellers (rotatable thrusters) driven by combustion engines through a toothed, electric or hydrostatic transmission

❖ propulsion system fitted with cycloidal (Voith- Schneider) propellers

❖ propulsion system fitted with water jet propellers.

Construction of inland waterways ships and their propulsion systems decisively depend on depth of waterways in which a given ship is to sail, as well as on dimensions of sluices existing in the waterways, and also on other conditions including ecological ones.

Below are presented basic design assumptions and selected design concepts of propulsion system for an inland waterways passenger ship intended for sailing on a shipping route of the minimum water depth of 1.2 m.

BASIC DESIGN ASSUMPTIONS AND CHOICE OF PROPULSION SYSTEM

The to-be-designed propulsion system is intended for the passenger ship of the following technical parameters :

★ overall length   L   = 56 m
★ overall breadth   B   = 9 m
★ draught   d   = 1 m
★ ship displacement ∇ = 440 t   for   d = 1m
★ assumed ship speed   V = 14 km/h   at   d = 1m
★ required power output   P = 300 kW

The required very small draught of the ship is an important limitation in searching for a suitable propulsion system. Certainly it cannot be a propulsion system using cycloidal propellers which are located under the ship's hull. Ships driven by water jets fairly well operate in shallow waters. However such drive is unfavourable from the ecological point of view. A large water stream sucked out from under ship's bottom and thrown overboard with a great velocity destroys bottom and side structures of the waterway and biological live existing there. In this case the factor has been deemed so important that it was decided to exclude the water jet propulsion system from further considerations.

Hence only the systems fitted with screw propellers have been taken into account. As the propeller is assumed to operate in non-cavitating range, its appropriate diameter should be greater than 1.4 m. In the case of two propellers used e.g. in Schottel rotatable thrusters the diameter of each of them might be a little smaller, equal to about 1.35 m.

Due to the small draught of the ship the above mentioned values of propeller diameter are not acceptable. Therefore it

was deemed necessary to apply a double-propeller propulsion system. This way it would be possible to decrease the diameter of the propellers to such an extent as to decrease its value to 0.83 – – 0.85 m in the case of placing them in Kort's nozzles, being still large enough to transfer the assumed power. The outer diameter of the nozzles would then exceed a little the draught of 1 m, but if ship's hull form is suitably corected it will not be a problem. Such solution has many advantages. The double-propeller propulsion system provides higher ship's manoeuvrability and reliability. Location of the propellers inside the nozzles significantly lowers risk of catching the propeller's blade on the bottom that usually results in a failure and necessity of replacement of the propeller. Ducting the propellers also lowers unfavourable influence of screw race on the waterway bottom structure.

An additional improvement of reliability of the system and its simplification can be obtain by applying the fixed-pitch propeller. However it requires to provide the system with capability of changing magnitude and direction of rotational speed of the propeller shaft, that can be realized in the simplest way by a hydrostatic or electric transmission included in the propulsion system.

Further advantages can be achieved by replacing the fixed nozzle with pivotable one, and even better by using a rotatable thruster. This makes it possible to resign from applying the traditional rudder and in consequence to significantly decrease gabarites and weight of the device and simultaneously to improve ship's manoeuvrability.

Taking into account the above presented factors one decided to elaborate conceptual design projects of two solutions of the propulsion system fitted with rotatable thrusters, the most technically justified in the opinion of these authors, namely :

◆ combustion-electric one fitted with typical asynchronous squirrel-cage electric motors and frequency converters making stepless control of rotational speed of fixed propeller possible

◆ combustion-hydraulic one fitted with hydrostatic transmission.

COMBUSTION-ELECTRIC PROPULSION SYSTEM

The elaborated combustion-electric main propulsion system of the ship in question is presented in Fig.1 and 2 in two versions differing to each other mainly by size of electric motors and way of their positioning.

Three electric generating sets were applied; each of them consisted of a four-stroke combustion engine driving a three-phase synchronous generator.

The total power output of the generating sets fully covers power demand for propelling and steering the ship. The output of the third generating set suffices to cover the assumed power demand of other consumers. So produced energy is delivered to the main switchboard. From here its main part goes to the frequency converters and next to the three-phase asynchronous electric motors driving the fixed screw propellers through the toothed intersecting-axis gear.

In the first version of the system in question, shown in two axonometric projections in Fig.1, have been applied the electric motors in vertical position, that made it possible to obtain a modular construction of rotatable thruster, more compact and having relatively small gabarites. The drive is transmitted from the motors to the propeller shaft through the one-stage toothed gear placed inside the pod (electric podded propulsor) of rotatable thruster under water. Its reduction ratio is small because of a limited size of the pod, that makes it necessary to use a four-pole medium-speed electric motor.
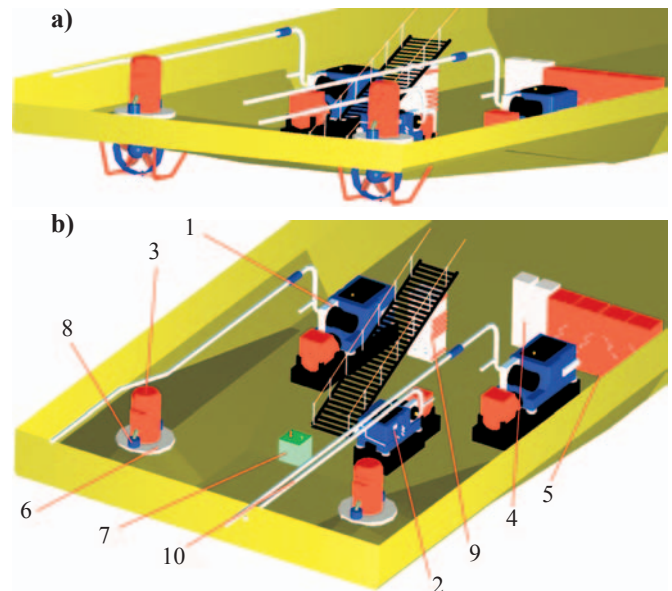
Fig. 1. *View of an example arrangement of the main components of the combustion-electric propulsion system fitted with the electric motors in vertical position .*

Notation : 1 – electric generating set, 2 – auxiliary electric generating set, 3 – electric three-phase asynchronous cage motor driving the propeller, 4 – frequency converter, 5 – main switchboard, 6 – rotatable thruster, 7 – hydraulic unit for supplying hydraulic motors, 8 – hydraulic motor fitted with planetary gear to drive the mechanism rotating the column of rotatable thruster, 9 – central „outboard water – fresh water" cooler, 10 – exhaust piping with silencers .

The ship steering functions are realized by rotating the column of rotatable thruster by an arbitrary angle around the vertical axis. To this end were used two hydraulic motors of a constant absorbing capacity, driving the column through toothed gears. The motors are fed from a constant capacity pump placed in the oil tank system.

A drawback of the solution is that the upper surface of the electric motor sticks out a little over the first deck of the ship (not shown in the figure). Another unfavourable feature is that the mass centre of electric motors is located high and shifted aft.

In the second version shown in Fig.2. the electric motors were placed in horizontal position. In consequence it was necessary to use a two-stage reduction gear of „Z" type. This way
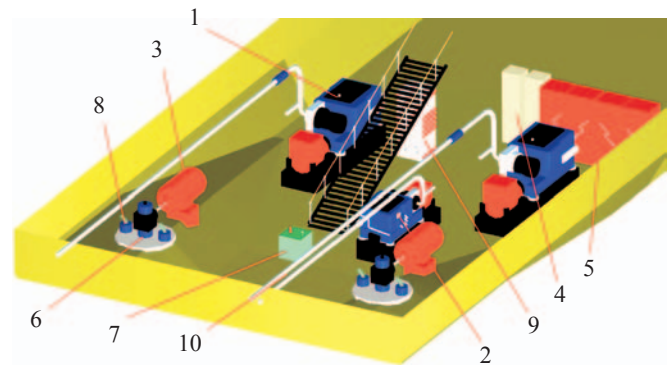
Fig. 2. *View of an example arrangement of the main components of the combustion-electric propulsion system fitted with the electric motors in horizontal position .*

Notation : 1 – electric generating set, 2 – auxiliary electric generating set, 3 – electric three-phase asynchronous cage motor driving the propeller, 4 – frequency converter, 5 – main switchboard, 6 – rotatable thruster, 7 – hydraulic unit for supplying hydraulic motors, 8 – hydraulic motor fitted with planetary gear to drive the mechanism rotating the column of rotatable thruster, 9 – central „outboard water – fresh water" cooler, 10 – exhaust piping with silencers .

the total reduction ratio could be greater resulting in possible application of two-pole electric motors of twice higher rotational speed, smaller and somewhat lighter. However it should be stressed that such solution is sometimes characterized by significant displacements of motor's shaft axis against rotatable thruster, caused by ship's hull deformations in heavy weather conditions. In order to eliminate the unfavourable influence of the deformations on operation of the toothed gear a flexible connection of the motor shaft and gear shaft by means of a Cardan coupling, was provided for.

Though such solution makes the construction more complex and of greater gabarites, it does not lower weight of the construction but only provides more favourable location of its centre of gravity.

COMBUSTION-HYDRAULIC PROPULSION SYSTEM

Fig.3 shows the propulsion system fitted with hydrostatic transmission, described in detail in [1]. To simplify the drawing the oil piping and other auxiliary devices of power plant have been omitted. The system is composed of two identical, mutually independent sub-systems; each of them is driven by the high-speed combustion engine (2). The engine directly drives : the main oil pump of variable capacity (4) and through the mechanical gear (3), the oil pump of constant capacity (not shown in the figure) for driving the rotation mechanism of the rotatable thruster, as well as the three-phase synchronous electric generator (5).
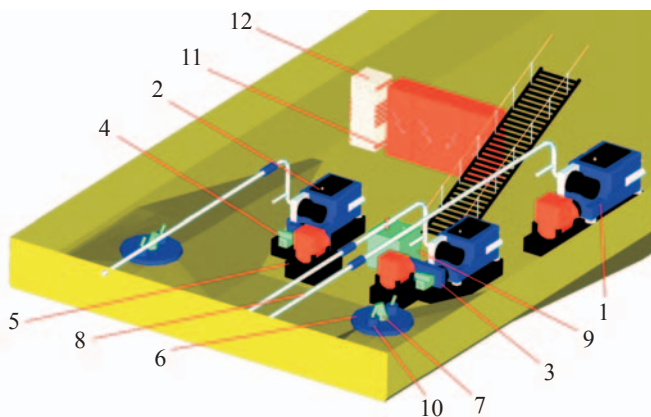

Fig. 3. *View of an example arrangement of the main components of the combustion-hydraulic propulsion system .*

Notation : 1- electric generating set, 2 – combustion engine, 3 – mechanical gear, 4 – the main pump unit to drive the propeller, 5 – electric generator, 6 – rotatable thruster, 7 – hydraulic motor driving the propeller, 8 – exhaust piping with silencers, 9 – hydraulic oil supplying unit, 10 – hydraulic motors to rotate the rotatable thruster around vertical axis, 11 – electric switchboard, 12 – central „outboard water – – fresh water" cooler .

The main oil pump (4) feeds the hydraulic motor of constant absorbing capacity (7). The motor drives, through the toothed bevel gear, the fixed propeller located within pivotable nozzle of the rotatable thruster (6). In this case the application of a fixed propeller was justified by making it possible to steplessly control speed and direction of rotation of the hydraulic motor. This is realized by changing the capacity of the pump (4) and oil pumping direction. The control system of the variable capacity pump is fed from a small pump installed at the main pump.

The system was provided with one large oil tank (9) and one central „outboard water – fresh water" cooler (12) that made it possible to reduce space of the ship power plant as well as a number of its auxiliary devices. The electric generating set (1) was applied to satisfy electric energy demand of other consumers.

COMPARATIVE ANALYSIS OF THE SYSTEMS

Final choice of the most favourable system is not an easy task as it must take into account a broad range of various factors including first of all: manoeuvrability, reliability, initial and operational costs, as well as area and space occupied by the system, its mass, location of its centre of gravity etc.

In Tab. 1-3 and diagrams (Fig.4,5) are presented some important data concerning the features and costs of the considered propulsion systems, which are supposed to make decision--taking easier.

As it follows from the given data both variants of combustion-electric system are very similar. However some rather important differences between them dealing with constructional problems not clearly indicated in the tables, do exist. The horizontal position of electric motors, as compared with vertical one, results in the necessity of application of the second stage of the bevel gear, additional shaft and couplings between the gear and motor, that makes the construction more complicated and real initial cost of rotatable thruster greater. Moreover the area occupied by the motor increases, however in that region it probably would not be used for other purposes.

The vertical position of the electric motor is, in the solution, a disadvantage resulting from a too-large height of the motor fixed on the rotatable thruster, not fitting under the deck. However its importance may be effectively reduced by a suitable arrangement of shipboard equipment in that region.

A greater number of even more important differences can be revealed by comparing both systems to each other : combustion-electric and combustion-hydraulic one.

Fig. 4. Comparison of mass of the presented propulsion systems : 1 – combustion-electric one with electric motors in vertical position, 2 – combustion-electric one with electric motors in horizontal position, 3 – combustion-hydraulic one .
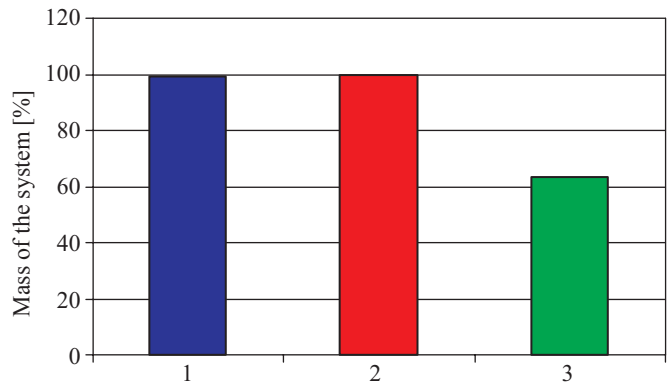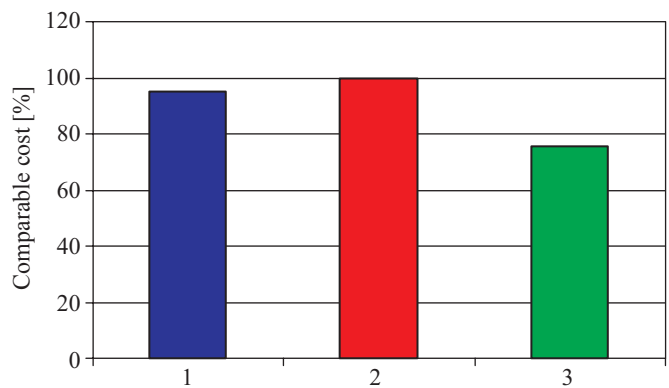

Fig. 5. Comparison of initial costs of the presented propulsion systems : 1 – combustion-electric one with electric motors in vertical position, 2 – combustion-electric one with electric motors in horizontal position, 3 – combustion-hydraulic one .

Tab. 1. Parameters and prices (costs) of the units of the combustion-electric propulsion system with electric motors located in vertical position .

Name of unit	Gabarites	Number	Mass : of one unit / total [kg]	Volume [m³] / area [m²]	Gross price (cost) : of one unit / total [EURO]
Electric generating set of 240 kW output : **IVECO GE 8210SRM45**	2737x1150x1371	2	2820 / 5640	8.63 / 6.30	57050 / 114100
Electric generating set of 112 kW output : **IVECO GE 8361SRM32**	2309x720x1280	1	1950 / 1950	2.13 / 1.66	37100 / 37100
Electric motor of 200 kW power : **EMIT SVgm 315 mL4**	1210x600x800	2	1120 / 2240	1.16 / 0.96 not accounted for in calculations *	6500 / 13000
Frequency converter : **Danfoss VLT**	370x420x1600	2	200 / 400	0.50 / 0.31	18000 / 36000
Hydraulic oil tank unit	500x500x700	1	300 / 300	0.15 / 0.25	
Rotatable thruster		2	910 / 1820		54000 / 108000
Total			/12350	11.41 / 8.52	/~308200

Tab. 2. Parameters and prices (costs) of the units of the combustion-electric propulsion system with electric motors located in horizontal position .

Name of unit	Gabarites	Number	Mass : of one unit / total [kg]	Volume [m³] / area [m²]	Gross price (cost) : of one unit / total [EURO]
Electric generating set of 240 kW output : **IVECO GE 8210SRM45**	2737x1150x1371	2	2820 / 5640	8.63 / 6.30	57050 / 114100
Electric generating set of 112 kW output : **IVECO GE 8361SRM32**	2309x720x1280	1	1950 / 1950	2.13 / 1.66	37100 / 37100
Electric motor of 200 kW power : **EMIT Sgm 315 mL2**	1200x1000x615	2	1100 / 2200	1.48 / 2.4 not accounted for in calculations *	18000 / 36000
Frequency converter : **Danfoss VLT**	370x420x1600	2	200 / 400	0.50 / 0.31	5200 / 10400
Hydraulic oil tank unit	500x500x800	1	300 / 300	0.20 / 0.25	
Rotatable thruster		2	980 / 1960		60000 / 120000
Total			/12450	11.41 / 8.52	/~317600

Tab. 3. Parameters and prices (costs) of the units of the combustion-hydraulic propulsion system with hydrostatic transmission .

Name of unit	Gabarites	Number	Mass : of one unit / total [kg]	Volume [m³] / area [m²]	Gross price (cost) : of one unit / total [EURO]
Combustion engine of 220 kW output : **IVECO CURSOR 300**	1770x935x1030	2	900 / 1800	3.41 / 3.31	24500 / 49000
Electric generating set of 220 kW output : **IVECO GE8210SRM36**	2975x1110x1940	1	2520 /2520	6.41 / 3.30	47160 / 47160
Hydraulic pump of 252 kW maximum output : **Rexroth A4VSG 180**	350x300x220	2	114 / 228	0.05 / 0.21	12000 / 24000
Hydraulic motor of 220 kW maximum output : **Rexroth A2FM 250**	224x280x250	2	73 / 146	0.03 / 0.13 not accounted for in calculations *	5368 / 10736
Electric generator of 40 kW output : **Leroy – Somer 42.2VL8**	615x450x450	2	165 / 330	0.25 / 0.55	3000 / 6000
Hydraulic oil tank unit	1000x1000x1300	1	1050 / 1050	1.23/ 1	
Rotatable thruster		2	900 / 1800		54000 / 108000
Total			/ 7874	11.31 / 8.37	/~244900

* This unit does not occupy any useful space of the power plant

As far as the broadly understood ship's manoeuvrability is concerned the propulsion system with hydrostatic transmission shows more advantages out of which the following are most important :

➢ better protection of the propulsion system against overloading that results in much higher reliability and durability of its units especially the bevel gear

➢ more accurately and faster realized manoeuvers that mainly results from many times smaller inertia moments of the hydraulic motors as compared with those of electric ones.

Successive advantages of the combustion-hydraulic system are its smaller weight and gabarites. They first of all result from several times smaller mass of the hydraulic motors and space occupied by them against those of the electric motors of the same power. As results from the data included in the tables the masses differ to each other almost fifteen times. Another source of the merits is the application of the high-speed combustion engines for driving the hydraulic pumps, having rotational speed much higher than that of the electric generating sets used in the combustion-electric propulsion system. The features are especially favourable in the case of small vessels especially those intended for sailing in shallow waters.

Another important advantage of the system fitted with hydrostatic transmission is its smaller initial cost amounting to less than 77% of that of the remaining systems in question.

An important drawback of the considered system is its higher operational costs. They mainly result from a lower efficiency of the system. From the so far performed analyses it results that the efficiency of the combustion-electric system is by about 5% higher than that of the combustion-hydraulic system, at rated values of their operational parameters. For this reason in the combustion-hydraulic system a somewhat higher total power output of combustion engines has been provided for. The need of periodical change of oil and filtering cartridges additionally rises operational costs.

FINAL REMARKS

All the three presented design variants of the ship propulsion systems satisfy the assumptions enumerated in *Introduction* and each of them could be applied to the designed ship. To choose the most favourable one out them is not an easy task. However these authors are convinced that the above presented analysis of basic features and costs of each of the systems certainly may help the principal designer of the ship in making a proper choice.

BIBLIOGRAPHY

1. Cz. Dymarski, G. Skorek: : *Energy balance of conceptual design of propulsion system with hydrostatic transmission for inland and coastal vessel*(in Polish). Faculty of Ocean Eng. and Ship Techn., Gdańsk University of Technology. Research Report No 154/E/2004
2. Cz. Dymarski; R. Rolbiecki – *Conceptual design of propulsion and control system with hydrostatic transmission for inland vessel*(in Polish). Faculty of Ocean Eng. and Ship Techn., Gdańsk University of Technology. Research Report No 164/E/2004
3. Cz. Dymarski: *An azimuthing combustion-hydraulic propulsion system for inland vessel*. Marine Technology Transaction (Technika Morska), Vol. 16, 2005
4. Information pamphlets and offer materials of the following companies: KaMeWa, Lips, Schottel, Ulstein, Wartsila. Iveco Motors, Bosch Rexroth, Emit, Schottel, Leroy – Some .

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*C*onference

Research – Education – Technology

On 20-22 May 2005, under this slogan, Faculty of Mechanical Engineering, Gdańsk University of Technology, organized the international symposium which was a continuation of meetings of the Faculty's staff and representatives of German partnership scientific research centres.

25 years ago such meetings have started from the contact with Hochschule in Bremen and in the course of time the number of German participants has increased.

As Poland entered the European Union, the following program assumptions were announced for the Symposium of 2005 :

✪ *presentation of advances and latest achievements in mechanical engineering as to enable common applications for European grants*

✪ *experience and information transfer in the field of implementation of European curricula in academic education at technical universities*
✪ *discussing problems of industrial implementation of research results*
✪ *establishing new personal contacts and strengthening existing friendly relations between scientists*.

and also scientific workers from France and Great Britain took part in the Symposium.

The Symposium program contained presentation and discussion of 53 papers out of which 29 were submitted by the organizers, 8 by scientific workers from Stralsund University, and the rest by representatives of other scientific centres : 8 German, 2 French, and 1 British, as well as 2 Polish ones (Częstochowa University of Technology and Institute of Fluid Flow Machinery, Gdańsk).

Numerical simulation
of viscid flow around hydrofoil

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ABSTRACT

This paper presents results of application of a viscid fluid model to calculate flow around a finite-span hydrofoil. The presented calculations were performed with the use of SOLAGA software developed by this author. The used theoretical model of viscid liquid motion was described, consisted of averaged liquid motion equations and Spalart-Allmaras one-equation model of turbulence. Also, a numerical model based on the finite volume method was shortly presented. Calculation results were shown in the form of distribution diagrams of pressures, longitudinal component of velocity and longitudinal component of rotation velocity. Additionally, the presented characteristics of the lifting force coefficient and drag force coefficient were compared with experimental data.

Keywords : viscid flow around hydrofoil, Spalart-Allmaras model, Finite Volume Method, SOLAGA

INTRODUCTION

Hydromechanical calculations of ship screw propellers carried out by Polish research centres (Ship Design and Research Centre – Stock Company, Institute of Fluid Flow Machinery - Polish Academy of Sciences, and Gdańsk University of Technology) are mainly based on potential motion of liquid, i.e. such as used in vortex methods or surface panel methods. In recent years in shipbuilding have been often and often applied programs dealing with viscid liquid flow. The programs are based on the Reynolds Averaged Navier-Stokes Equation (RANSE) and turbulence model equations. Solvers based on the RANSE methods have been for years applied to calculate ship wake, and quite recently they have been used as „universal" programs for solving any hydromechanical problem.

The project under development, whose partial results have been presented in this paper, is aimed at elaboration of an algorithm and computer program for calculating the viscid flow around ship propellers and hydrofoils. This author is convinced that development of a computer program specialized in calculating objects of one kind will make it possible to obtain - - in the future - better results against those achievable from the „universal" solvers widely applied (mainly abroad).

In this paper are presented calculation results obtained by means of the SOLAGA computer software under development within the frame of the project in question. The test calculations were performed for a rectangular hydrofoil of NACA66-9 profile and the aspect ratio $\Lambda = 6$.

VISCID FLUID MOTION EQUATIONS

The closed system of fluid motion equations is based on two principles : the principle of mass conservation and principle of conservation of momentum.

The equation of mass conservation formulated for inviscid fluid is as follows :

$$\frac{\partial u_i}{\partial x_i} = 0 \tag{1}$$

And the equation of conservation of momentum has the following form :

$$\rho \frac{\partial u_i}{\partial t} + \rho u_i \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(2\mu s_{ji}\right) \tag{2}$$

where :

$$s_{ji} = \frac{1}{2}\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right) \tag{3}$$

is the strain - rate tensor and :

p	-	pressure
ρ	-	density
μ	-	dynamic viscosity coefficient
x_i , u_i	-	components of location vector and velocity vector, respectively.

The above given equations fully describing the behaviour of Newtonian incompressible liquid are applicable in calculating the flows characterized by small values of Reynolds number, i.e. up to about $10^3 \div 10^4$.

In the case of flows of a greater Reynolds number, to apply the equations is not possible due to the scale of phenomena occurring in the fluid.

In the engineering problems associated with flow of water, Reynolds numbers as usual greatly exceed the value of 10^4. In ship hydromechanics its value is as a rule contained within the interval of $10^6 \div 10^8$, and in this connection instead of Eqs (1) and (2) their averaged equivalents are used.

The instantaneous velocity vector $u_i(x,t)$ can be presented as a sum of the average velocity $U_i(x)$ and the fluctuation $u_i'(x,t)$:

$$u_i(x,t) = U_i(x) + u_i'(x,t) \qquad (4)$$

In a similar way the instantaneous pressure field $p(x,t)$ can be described :

$$p(x,t) = P(x) + p'(x,t) \qquad (5)$$

Applying the above notation used to the set of Eqs (1),(2) one obtains the averaged equations of motion [6] :

$$\frac{\partial U_i}{\partial x_i} = 0 \qquad (6)$$

$$\rho \frac{\partial U_i}{\partial t} + \rho U_i \frac{\partial U_i}{\partial x_j} = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j}\left(2\mu S_{ji} - \rho \overline{u_j' u_i'}\right) \quad (7)$$

In the averaged momentum conservation equation the term $-\rho \overline{u_i' u_j'}$ (called *Reynolds stress tensor*) appears. In order to compute the tensor it is necessary to introduce additional equations which are called *turbulence model*. A turbulence model is selected respective to a considered kind of flow and an assumed calculation accuracy; calculation time is also one of the important factors - the more complex model the longer time of calculations.

In the presented calculation program the Spalart-Allmaras one-equation model was used, introduced for calculating hydrofoils.

The turbulent stress tensor is calculated on the basis of Boussinesq's hypothesis which assumes that the Reynolds stresses can be expressed by means of the turbulent viscosity and mean strain - rate tensor :

$$\tau_{ij} = \rho \overline{u_i' u_j'} = \rho \nu_T \left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right) \qquad (8)$$

The kinematic turbulent viscosity ν_T is calculated from the formula :

$$\nu_T = \tilde{\nu} f_{v1} \qquad (9)$$

And, the modified turbulent viscosity $\tilde{\nu}$ is calculated with the use of the transport equation :

$$\frac{\partial \tilde{\nu}}{\partial t} + U_j \frac{\partial \tilde{\nu}}{\partial x_j} = c_{b1} \tilde{S}_{SA} \tilde{\nu} - c_{w1} f_w \left(\frac{\tilde{\nu}}{d}\right)^2 + $$
$$+ \frac{1}{\sigma} \frac{\partial}{\partial x_k}\left[(\nu + \tilde{\nu}) \frac{\partial \tilde{\nu}}{\partial x_k}\right] + \frac{c_{b2}}{\sigma} \frac{\partial \tilde{\nu}}{\partial x_k} \frac{\partial \tilde{\nu}}{\partial x_k} \qquad (10)$$

The values of the model's coefficients and the relations between the coefficients are given below :

$$c_{b1} = 0.1355 \ , \ c_{b2} = 0.622 \ , \ c_{v1} = 7.1 \ , \ \sigma = 2/3 \quad (11)$$

$$c_{w1} = \frac{c_{b1}}{\kappa^2} + \frac{1 + c_{b2}}{\sigma} \qquad (12)$$

$$c_{w2} = 0.3 \ , \ c_{w3} = 2 \ , \ \kappa = 0.41$$

$$f_{v1} = \frac{\chi^3}{\chi^3 + c_{v1}^3} \ , \ f_{v2} = 1 - \frac{\chi}{1 + \chi f_{v1}} \qquad (13)$$

$$f_w = g \left[\frac{1 + c_{w3}^6}{g^6 + c_{w3}^6}\right]^{1/6}$$

$$\chi = \frac{\tilde{\nu}}{\nu} \ , \ g = r + c_{w2}(r^6 - r) \ , \ r = \frac{\tilde{\nu}}{\tilde{S}_{SA} \kappa^2 d^2} \quad (14)$$

$$\tilde{S}_{SA} = S_{SA} + \frac{\tilde{\nu}}{\kappa^2 d^2} f_{v2} \ , \ S_{SA} = \sqrt{2\Omega_{ij}\Omega_{ij}} \qquad (15)$$

where :
Ω_{ij} – rotation tensor
d – distance to the nearest surface of the flow-around object .

$$\Omega_{ij} = \frac{1}{2}\left(\frac{\partial U_i}{\partial x_j} - \frac{\partial U_j}{\partial x_i}\right) \qquad (16)$$

The assumed initial and boundary conditions

The value of the modified turbulent viscosity $\tilde{\nu}$ equal to 0.1ν (where : ν – coefficient of molecular kinematic viscosity) was assumed at inlet. On the hydrofoil surface $\tilde{\nu} = 0$ is assumed as the turbulent viscosity in the flow close to wall amounts to zero. [2].

NUMERICAL MODEL

The below presented equations are solved in a discrete way – they are transformed into a set of algebraic equations formulated for each node of calculation grid. Depending on specificity of a considered problem one can use one of the following space discretization method :

- Finite Differences Method (FDM) [4]
- Finite Element Method (FEM) [3]
- Finite Volume Method (FVM) [4].

In the SOLAGA software the discretization is performed by means of the FVM which provides a great freedom in selecting a kind of calculation grid, that makes it possible to calculate flow around objects of complex geometry.

Discretization of computation space. The Finite Volume Method (FVM)

The initial point to formulate the FV Method is the integral form of conservation equations, namely a considered calculation space is divided into a finite number of control volumes and for each of them relevant behaviour equations are formulated. Eq. (17) shows the general form of the conservation equation of the scalar quantity ϕ, given in the integral form :

$$\int_S \rho \phi \mathbf{V} \cdot \mathbf{n} dS = \int_S \Gamma \, \text{grad}\, \phi \cdot \mathbf{n} dS + \int_\Omega q_\phi d\Omega \qquad (17)$$

where :
$\mathbf{V}$ – velocity vector
ϕ – field scalar function
$\mathbf{n}$ – vector normal to the control element surface S
Γ – diffusivity
q_ϕ – source of the quantity ϕ.

The surface and volume integrals appearing in the above given equation are calculated by means of approximate methods. Values of the field function between computation nodes are obtained by using interpolation.

Calculation of surface and volume integrals

The surface and volume integrals appearing in Eq. (17) are calculated by means of the below described quadratures.

The integral of the function f on the surface S can be developed as follows (Fig. 1) :

$$\int_S f\,dS = \sum_k \int_{S_k} f\,dS \qquad (18)$$

where :
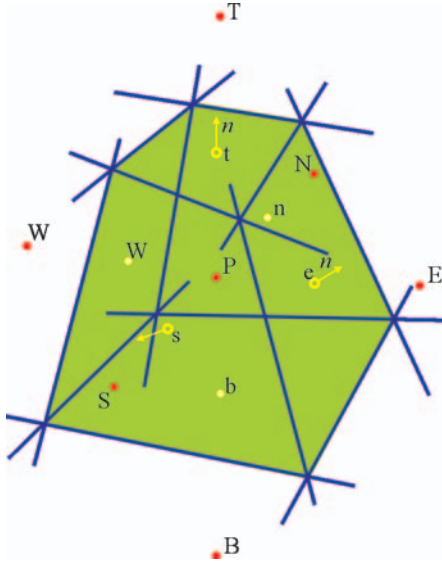S_k - surface of the wall with the index k (k = w, e, s, n, b, t).

Fig. 1. Control element of 3D grid containing the node P. The nodes : W, E, S, N, B, T of the neighbouring elements and the central points of the element walls w, e, s, n, b, t are also depicted.

The integral of the function f on the single wall S_e is approximately calculated by applying the central point method :

$$\int_{S_e} f\,dS \approx f_e S_e \qquad (19)$$

where : f_e - value of the integrand in the central point *e* of the surface S_e .

The volume integrals are calculated in an analogical way; the integral of the field function q over the volume Ω can be calculated as follows :

$$Q_P = \int_\Omega q\,d\Omega \approx q_P \Omega \qquad (20)$$

where : q_P - value of the function q in the central point P.

Field function values in the central points of control volumes (nodes) are obtained directly from solving the set of equations, whereas field function values on the control volume surface are calculated by means of appropriate interpolation schemes.

Interpolation schemes

Carrying out calculations with the use of SOLAGA software one can apply two kinds of interpolation schemes :

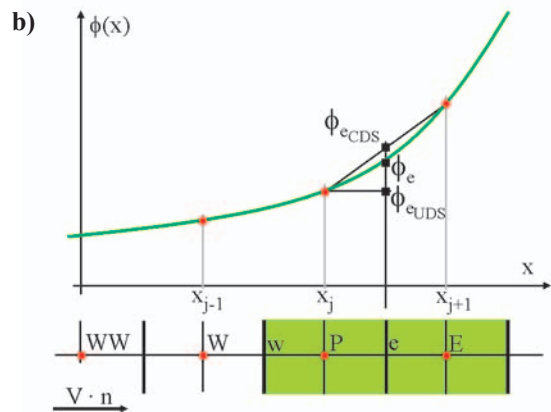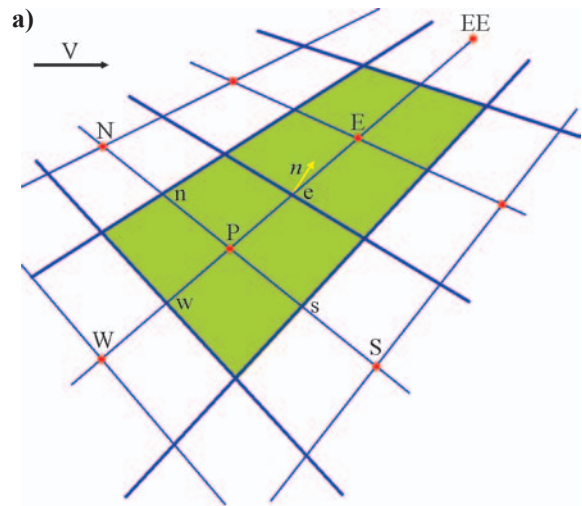✴ *Upwind* interpolation (UDS)
✴ *Linear* interpolation (CDS).

a)

b)

Fig. 2.a) *Cross-section through 3D calculation grid. **Note** : control elements with the nodes **P** and **E** and the wall located between them and containing the central point **e**, are marked grey. Value of the function ϕ in this point is obtained by using interpolation.*
In **Fig. 2.b)** *are shown principles of operation of the interpolation schemes: UDS – upwind interpolation, CDS – linear interpolation.*

In the *upwind* method, transport of the medium described by the function ϕ is assumed to be realized mainly by convection – value of the function in the central point of the element's wall is equal to that in the neighbouring node located „upwind" the medium flow. Value of the function ϕ in the point *e* (Fig.2) is calculated by using the following formula :

$$\phi_{e,UDS} = \begin{cases} \phi_P & \text{if } (\mathbf{V}\cdot\mathbf{n})_e > 0 \\ \phi_E & \text{if } (\mathbf{V}\cdot\mathbf{n})_e < 0 \end{cases} \qquad (21)$$

The *upwind* scheme is unconditionally stable and does not lead to oscillating solutions. Its drawback consists in a large numerical diffusion and low accuracy (of 1st order).

More accurate results can be obtained by using the linear interpolation scheme (CDS) based on the assumption that the function between the points P and E varies linearly (Fig.2 b). Value of the function ϕ in the point *e* is calculated as follows :

$$\phi_{e,CDS} = \phi_E \lambda_e + \phi_P (1 - \lambda_e) \qquad (22)$$

where : λ_e - linear interpolation coefficient calculated by means of the following formula :

$$\lambda_e = \frac{|x_e - x_P|}{|x_E - x_P|} \qquad (23)$$

Eq. (22) is of the degree of 2nd-order accuracy. The CDS scheme is characterized by a much lower numerical diffusion than that of the *upwind* one. The drawback of the CDS scheme is its lower stability and susceptibility to generate oscillating solutions.

In order to avoid the solution instability the both schemes are connected together by introducing the so called blending factor $B \in \langle 0 ; 1 \rangle$. The interpolated value of the function ϕ in the point e is hence determined as follows :

$$\phi_e = (1 - B)\, \phi_{e,UDS} + B\, \phi_{e,CDS} \qquad (24)$$

where :

$\phi_{e,UDS}$ - value calculated by means of the UDS scheme
$\phi_{e,CDS}$ - value calculated by means of the CDS scheme.

This approach makes it possible to achieve a stable solution at maintaining a relatively high degree of calculation accuracy.

Numerical methods of solving non-stationary problems

In the case when considered problems have a non-stationary character it is necessary to apply the methods analogous to those used in solving initial problems for ordinary differential equations.

The problems associated with liquid flow are as a rule characterized by time-variability in spite of stationary boundary conditions, in the cases application of a non-stationary model is recommended. Such approach is especially justified in the case of calculation of rather non-streamlined objects where flow separation may occur.

Methods of solving initial problems of ordinary differential equations

After spatial discretization of the partial differential equation the set of ordinary differential equations is obtained in the following form :

$$\frac{d\vec{\phi}(t)}{dt} = \vec{F}\left[t, \vec{\phi}(t)\right] \ , \ \ \vec{\phi}(t_0) = \vec{\phi}^0 \qquad (25)$$

The simplest way of solving the above given equation is its integration within consecutive time intervals to obtain the solution for the successive time values $t_1 , t_2 , t_3 \ldots$

$$\int_{t_n}^{t_{n+1}} \frac{d\vec{\phi}(t)}{dt} dt = \vec{\phi}^{n+1} - \vec{\phi}^n = \int_{t_n}^{t_{n+1}} \vec{F}\left[t, \vec{\phi}(t)\right] dt \qquad (26)$$

The above given expression is accurate. Numerical methods for determining the quantity ϕ^{n+1} are classified with accounting for a way of calculation of the right-hand side integral. In the presented software two integration methods are applied : the *backward (implicit) Euler* method and *three time level* method. In the *Euler* method a value of the integrand within the whole interval $t \in \langle t_n , t_{n+1} \rangle$ is assumed equal to $\vec{F}[t_{n+1} , \vec{\phi}(t_{n+1})]$, see Fig.3a. Elements of the vector $\vec{\phi}$ in the successive time-step are calculated as follows :

$$\vec{\phi}^{n+1} = \vec{\phi}^n + \vec{F}\left(t_{n+1}, \vec{\phi}^{n+1}\right)\Delta t \qquad (27)$$

The *three time level* method consists in approximating the course of the function $\vec{F}[t_{n+1} , \vec{\phi}(t_{n+1})]$ by means of 2nd order parabola crossing the points t_{n-1} , t_n , t_{n+1} , see Fig.3b. The formula of the method is as follows :

$$\vec{\phi}^{n+1} = \frac{4}{3}\vec{\phi}^n - \frac{1}{3}\vec{\phi}^{n-1} + \frac{2}{3}\vec{F}\left(t_{n+1}, \vec{\phi}^{n+1}\right)\Delta t \qquad (28)$$

Both the mentioned methods are of implicit kind, i.e. that knowledge of values of its elements is necessary to calculate the vector $\vec{\phi}^{n+1}$. As a result of the application of one of the above described methods a set of m - equations is formed in every time step, where m stands for a number of calculation nodes. The equation set is solved in an iterative way by using the methods described below.
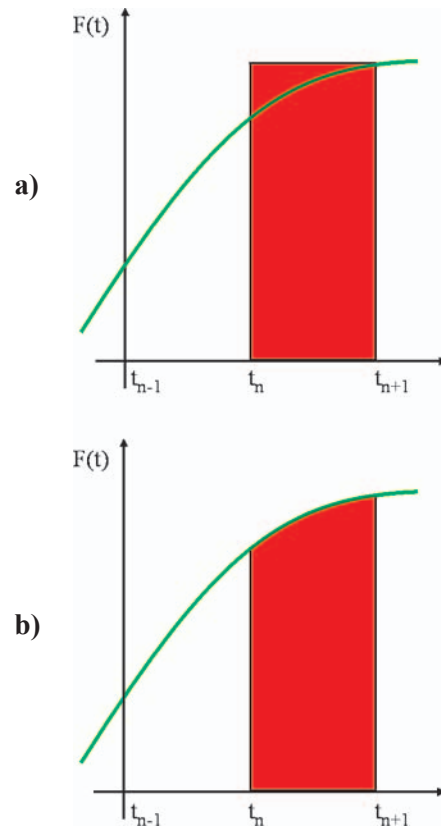
Fig. 3. *Numerical integration of equations for non-stationary problems :*
a) implicit Euler method, b) three time level method .

Methods of solving the sets of equations

As a result of spatial discretization of motion equations a set of algebraic equations formulated for each of the control volumes is obtained. The set, when linearized, is solved in an iterative way. In the software in question the algorithms based on the method of conjugate gradients are used : ICCG algorithm serves for solving the symmetrical matrices obtained from discretization of the Poisson equation (calculation of pressure corrections), and the unsymmetrical matrices are solved by means of Bi-CGSTAB algorithm. The above mentioned algorithms are described in [4].

TESTING CALCULATIONS

Computational data

The geometry of hydrofoil	Chord : $c = 0.2$ m Span : $w = 1.2$ m Profile : NACA 66-9
Angles of attack	0, 2, 4, 6, 8, 10, 12 degrees
Inflow velocity	V = 5 m/s

Model details

Turbulence model	Spalart-Allmaras (see Eqs $8 \div 16$)
Interpolation scheme	UDS and CDS (blending factor B = 0.5)
Time integral approximation scheme	Implicit Euler (1st order)
Time step	$0.002 \div 0.01$ sec
Number of control volumes	600 000

Results

Maps of pressure distribution on the hydrofoil plane of symmetry for various angles of attack are shown in Fig.4. And distribution of rotation in the wake behind the hydrofoil is shown in Fig.5. Distribution of the longitudinal component of rotation is presented in Fig.6.

Pressure [Pa]

(red)	-22000	(light blue)	-1600
(yellow)	-15200	(dark blue)	5200
(green)	-8400	(pink)	12000

Fig. 4. Pressure distributions on surface of hydrofoil and its plane of symmetry .

Velocity V$_x$ [m/s]

(red)	-1.0	(light blue)	3.8
(yellow)	0.6	(dark blue)	5.4
(green)	2.2	(pink)	7.0

Fig. 5. Distribution of longitudinal velocity component just over hydrofoil's surface, in its plane of symmetry, and on the plane normal to flow direction, distant by one chord length behind trailing edge of the hydrofoil .

Fig. 7. Coefficients of the lifting force C_L and the drag force C_D in function of the angle of attack. The experimental data are in accordance with [1].

CONCLUSIONS

The computational results presented in this paper may be concluded as follows :

❍ The calculated pressure distribution around hydrofoil is qualitatively similar to that obtained from experiment.

❍ The calculated distribution of longitudinal component of rotation behind the hydrofoil is similar to the rotation fields obtained from the experiments [5]. The tip vortex core is clearly visible. The strength of vorticity increases up along with the angle of attack.

❍ The coefficients of lifting force and drag force are in a good conformity with the experimental data especially in the range of angle of attack from 0 to 6 degrees. The critical point of the lifting force coefficient characteristics is predicted with the accuracy of about 1 ÷ 2 degrees.

Acknowledgement

NOMENCLATURE

C_D - drag force coefficient
C_L - lifting force coefficient
d - distance to the nearest surface of the flow - around object
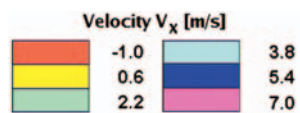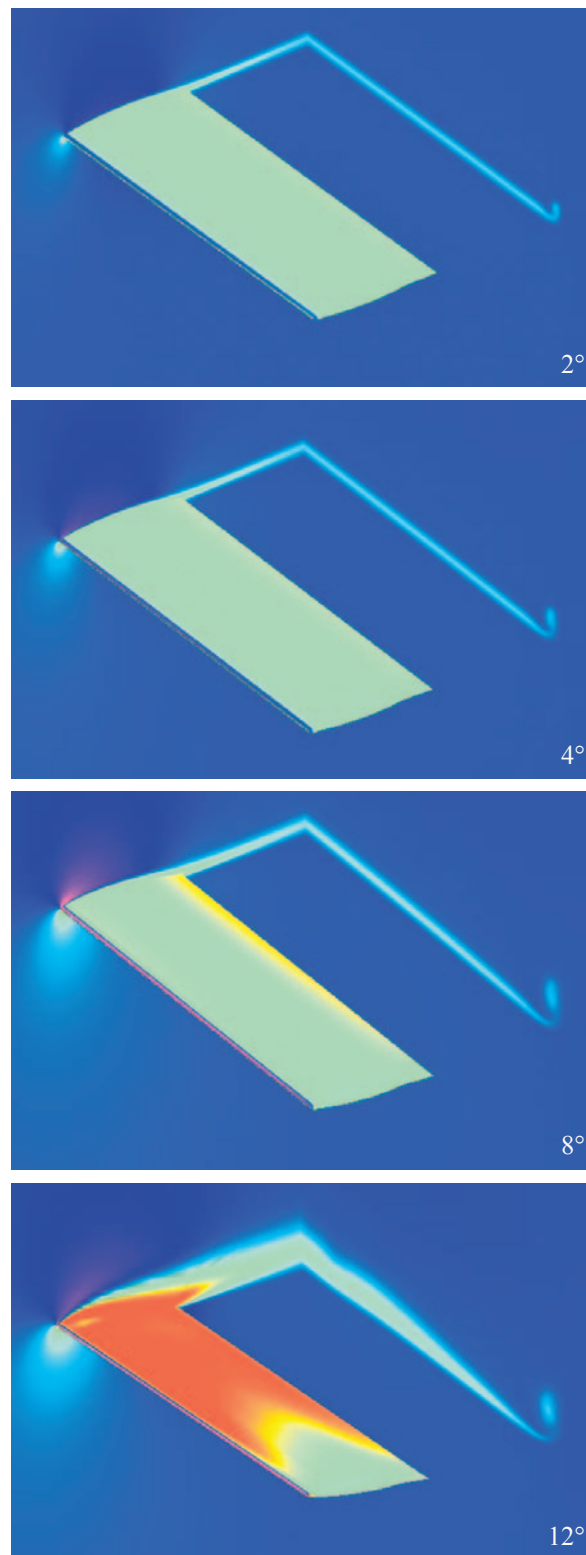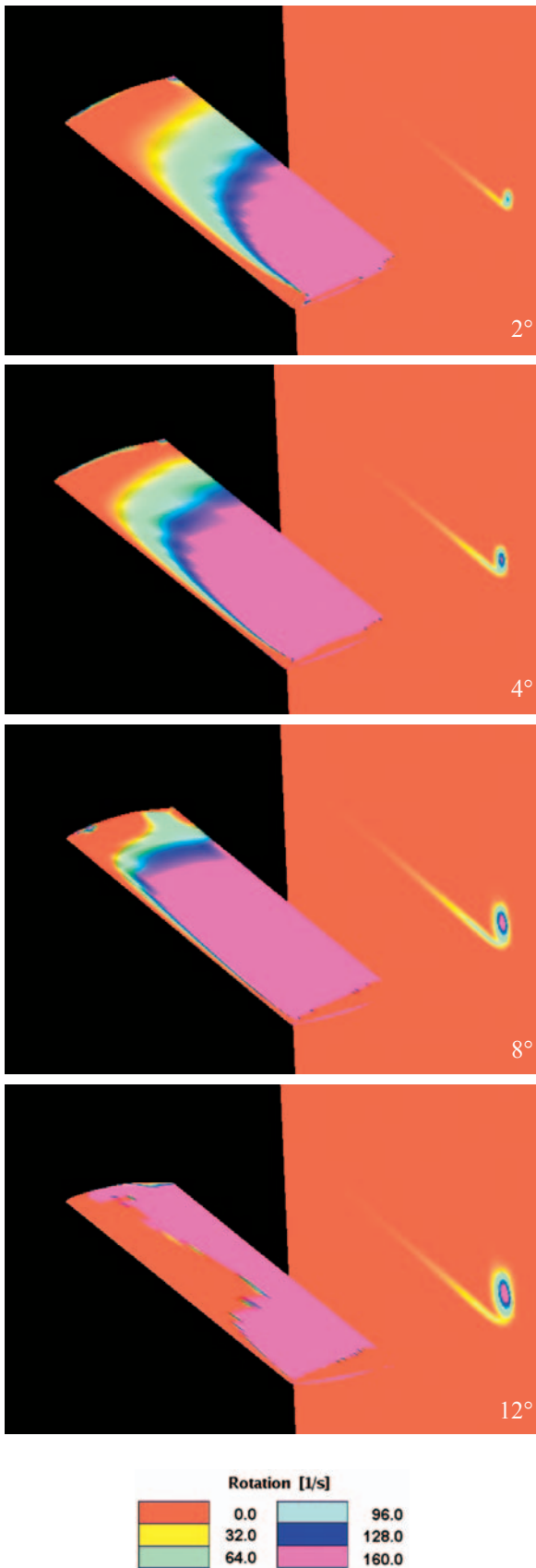f - field function which determines a given (diffusional and/or convectional) flow rate
$\vec{F}$ - vector of integrand functions of a set of ordinary differential equations (given in vectorial form)
n - vector normal to the surface S
p - instantaneous pressure
p' - pressure fluctuation
P - time-averaged pressure
q - function which determines field source
Q_P - total source in control element containing the central point P
S - control surface (which limits control element)
S_{ji} - time-averaged strain - rate tensor of deformations
t - time
t_n - t value in n-th step of calculations
u_i - instantaneous velocity component (in Cartesian notation)
u'_i - fluctuation of velocity component
U_i , U_j - time-averaged velocity components
V - velocity vector, see Eq.(17)
x - location vector

Fig. 6. *Distribution of longitudinal rotational velocity component on the plane normal to flow direction, distant by one chord length behind trailing edge of the hydrofoil. The multi-colour „spot" on the right-hand side shows distribution of rotation in the tip vortex core .*

The computational characteristics of the coefficients of lifting force and drag force are compared with the experimental data [1] in Fig.7.
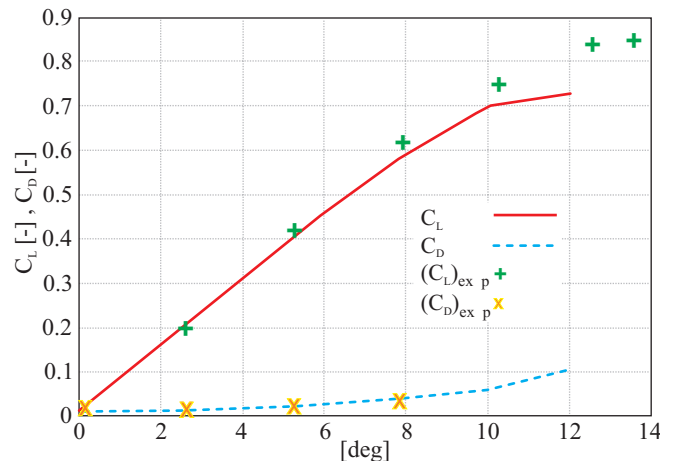
x_i - component of location vector
Γ - diffusion coefficient of the quantity ϕ
μ - dynamic viscosity coefficient of a liquid
ν - kinematic viscosity coefficient of a liquid
$\tilde{\nu}$ - turbulence model coefficient (turbulent modified viscosity), see Eq.(9)
ν_T - kinematic turbulent viscosity coefficient of a liquid
ρ - density
ϕ - field scalar function
$\bar{\phi}$ - vector of ϕ function values in nodes of calculation grid (for a discrete form of ϕ function)
ϕ_e - value of ϕ function in the point e
ϕ_E - value of ϕ function in the point E
$\phi_{e,UDS}$ - value of ϕ_e approximated by using UDS scheme
$\phi_{e,CDS}$ - value of ϕ_e approximated by using CDS scheme
ϕ_p - value of ϕ function in the point P
Ω - control element volume.

Acronyms

Bi-CGSTAB   - BiConjugate Gradient Stabilized method
ICCG   - Incomplete Cholesky Conjugate Gradient method

BIBLIOGRAPHY

1. Abbott I.H., von Doenhoff A.E. : *Theory of Wing Sections.* Dover Publications inc. New York, 1959
2. Blazek J. : *Computational Fluid Dynamics: Principles and Applications.* ELSEVIER. 2001
3. Chung T.J : *Computational Fluid Dynamics.* Cambridge University Press. 2002
4. Ferziger J.H., Peric M. : *Computational Methods for Fluid Dynamics.* Springer. Berlin, 1999
5. Koronowicz T. : *Rationality of Solving 3D Circulation Problems Exclusively with the Use of Navier-Stokes Equation.* TASK quarterly No 1/2002
6. Wilcox D.C.: *Turbulence Modeling for CFD,* DCW Industries. 2002 .

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*C*onference

PTNSS Congress 2005

On 25–28 September 2005 was held 1st International Congress on Combustion Engines organized by Polish Scientific Society of Combustion Engines (PTNSS), under the slogan :

The development of combustion engines

The Congress in which representatives participated of universities and scientific research centres as well as automotive industry firms from 9 European countries, Japan and USA, took place in Bielsko-Biała, a town in the mountainous, south-western region of Poland.

Its program contained 3 plenary sessions with 4 papers presented during each of them, under the slogans :

Automotive/Engine Technology Development (4 papers)
Advanced Engine Design & Performance (8 papers)

and 5 technical sessions covering the following groups of topics :

✦ Engine testing (28 papers)
✦ Emission (17 papers)
✦ Fuel injection (9 papers)
✦ Combustion process (9 papers)
✦ Modeling (8 papers)
✦ Alternative fuels (6 papers)
✦ Various subjects (4 papers)

The third part was the poster session devoted to presentation of 42 different elaborations. Among so many different papers 9 of them dealt with ship engines, namely :

★ *Ways to improve operational properties of lorry engines* by Janusz Mysłowski and Jaromir Mysłowski (Technical University of Szczecin)

★ *Universal research test of toxic exhausts from ship piston engines* – by L. Piaseczny and T. Kniaziewicz (Polish Naval University)
★ *Possibilities of recognizing faults in gas turbine engines on the basis of simulation of transitory processes* – by A. Adamkiewicz (Polish Naval University) and M. Dzida (Gdańsk University of Technology)
★ *Analysis of vibration parameters of marine gas turbine engines* – by A. Grządziela (Polish Naval University)
★ *Diagnostic examination of marine engines in the Polish Navy* – by Z. Korczewski (Polish Naval University)
★ *Construction of modern valve train mechanism for marine diesel engines* – by T. Lus (Polish Naval University)
★ *Investigations of carbon deposits on injector nozzles of marine diesel engines* – by J. Monieta and P. Wójcikowski (Maritime University of Szczecin)
★ *Research on influence of delivery of water to cylinders on combustion process parameters and exhaust toxicity of internal combustion engines* – by L. Piaseczny and R. Zadrąg (Polish Naval University)
★ *Approximation of the cylinder compression pressure of the marine engine by means of a multi-parameter model* – by S. Polanowski (Polish Naval University)

Also, the panel discussion on
„*Development trends of internal combustion engines*”
was carried out within the frame of the Congress.

EXPLO-DIESEL & GAS TURBINE'05

On 9-13 May 2005 under this heading was held 4th International Scientific Technical Conference organized by the Faculty of Ocean Engineering & Ship Technology, Gdańsk University of Technology, together with MAN-B&W DIESEL A/S.

In accordance with the Conference slogan :

Keeping diesel engines and gas turbines in movement with regard to environmental protection

the Conference aim was to make science-practice relations closer and to partricipate in creation of a forum for exchange cognitive and utilitarian information on designing, manufacturing and operating the self-ignition engines and gas turbines as well as machines and other devices necessary to maintain the engines running, with special accounting for : their power and pro-ecological qualities as well as durability, reliability, diagnostics and operational safety.

The program's intentions were realized by 50 papers published in the Conference proceedings, 25 of which were presented and 20 were demonstrated during two poster sessions, as well as by 6 presentations performed by representatives of the companies working a.o. in the field of marine engineering, namely :

➲ *Marine diesel engines and catalytic fines – a new standard to ensure safe operation* – by G. Astroem (ALFA LAVAL)

➲ *Activity profile* – by Ł. Rózga (PBP ENAMOR Ltd)

➲ *ME engine concept in front of environment protection demands of today and in the future* – by S. Henningsen (MAN-B&W DIESEL A/S)

➲ *The latest MAN-B&W DIESEL design achievements on the base of S65ME-C engine concept* – by A. Oestergaard (MAN-B&W DIESEL A/S)

➲ *Application of portable electronic indicators in operation of self-ignition engines* – by L. Tomczak (UNITEST)

➲ *Application of 3D visualization in marine training software* – by L. Tomczak (UNITEST).

The course of the Conference was very attractive as four first sessions including one poster session were held in a hotel at Międzyzdroje, a health resort on the coast of the Baltic Sea, and the 5th session on board a ferry calling at Copenhagen where the 6th and 7th sessions were arranged in the MAN-B&W DIESEL headquarter.

There was also an occasion to visit a very interesting museum of the company and to be acquainted with running stand tests on the original 4T50MX two-stroke engine. Next day, after return to Międzyzdroje the last four sessions had place including one poster session.

Worthmentioning that the Conferences in question have been characterized traditionally by a very valuable consistence of theoretical knowledge and research and production practice.

Representatives of 16 scientific research and design centres took part in the preparation of papers for the Conference. The greatest share in this had scientific workers of Gdańsk University of Technology, Polish Naval University, Gdynia Maritime University, Poznań University of Technology, Airforce Technical Institute and Maritime University of Szczecin, who participated in the preparation of 12, 10, 7, 6, 4, and 3 papers, respectively.

MAN - B&W DIESEL - Copenhagen R&D centre

On the application of the artificial neural network method to a neural simulator of steam turbine power plant

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ABSTRACT

In the paper a neural simulator of steam power unit is presented as an example of application of artificial neural networks (ANN) for modeling complex technical objects. A set of one-directional back-propagation networks was applied to simulate distribution of main steam flow parameters in the cycle's crucial points for a broad range of loading. A very good accuracy and short computation time was obtained. The advantages make the simulator useful for on-line diagnostic applications where short response time is very important. The most important features of the simulator, main phases of its elaboration and a certain amount of experience gained from solving the task was presented to make the practical application of the method in question more familiar.

Keywords : neural modeling and simulating, turbine power plants, on-line diagnostics

INTRODUCTION

Steam power unit or ship power plant is a very complex object. To know its technical state is crucial for carrying out its operation in an optimum way, in which diagnostics is of a great importance.

Today, apart from safety, the taking care of operational process quality to obtain long-term reduction of cost has become a priority. It consists in expanding times between overhauls at simultaneous maintaining the efficiency of devices on a constantly good level. This is on-line diagnostics which makes continuous controlling the technical state of objects under operation possible. As it brings large economical profits the diagnostics becomes more and more important and its dynamical development can be thus explained.

Therefore is needed a device which would be able to accurately determined operational parameters of a given object so fast as to make it possible to compare them with current ones. To achieve that determination time of a correct operational standard should be of the order of milliseconds (resulting from sampling frequency of measuring systems). Heat flow diagnostics of steam power units is based on advanced analytical models. However because of their long computation time they can be used in off-line mode only. It means that periodic control of technical state of an object can be performed on the basis of earlier collected data.

The neural simulator operates as a black box and artificial neurons acts here instead of sophisticated models. Its response process consists in simple mathematical operations. Due to this fact a neural simulator is more primitive than an analytical one but it provides standard operational parameters of a given object very fast and with good accuracy that justifies its application to on-line diagnostics.

PHASES OF ELABORATION OF THE NEURAL SIMULATOR

Choice of a simulated object

A standard steam power unit of 200 MW output fitted with a modernized TK 200 turbine was selected as the object to be simulated (Fig.1). Such selection has been justified by the wide application of units of the kind in Polish electro-energy system.

Training data acquisition

In the ANN method a fundamental thing is to have an appropriate set of training data as the rules written in neural model structure are generated on their basis. During training the network finds only relations between a given "input" and "output", contrary to an analytical model elaborated on the basis of universal laws of mathematics and physics where experimental data serve only to control if theoretical laws are in compliance with reality.

Hence to apply the ANN method it is necessary to collect in advance a huge amount of experimental data for training the network.

For lack of operational data of a real steam power unit this author made use of DIAGAR software [2] which served as a source of data for elaborating the neural simulator in question. Such situation where an analytical simulator provides training data is very advantageous as it makes it possible to generate an almost arbitrary set of images for training the network.

Fig.2 shows schematic diagram of computations of the object taken into account in DIAGAR software. The main steam jet is marked red and regenerative steam extractions are signed with Roman numerals.
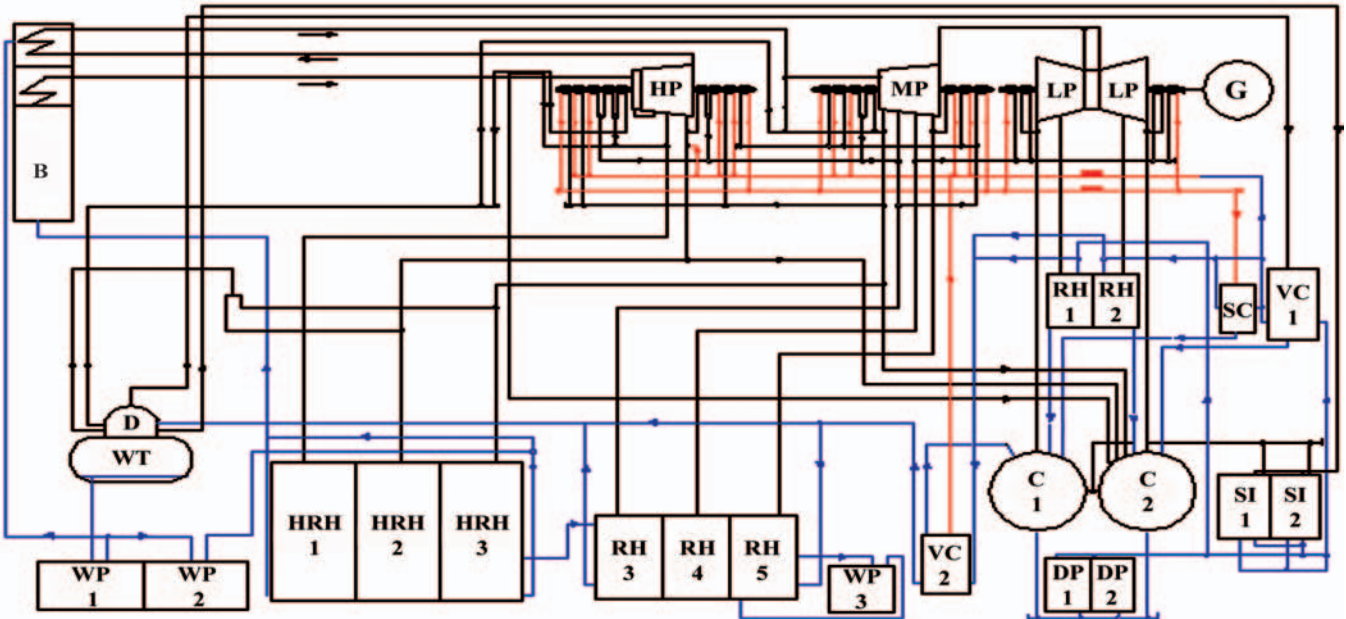
Fig. 1. Simplified schematic diagram of the steam power plant, where : **B** – Boiler, **C** - Constant pressure condensers, **D** – Degasifier, **DP** - Drip pumps,
G - Electric generator, **HP** - High Pressure unit of condensing turbine, **HRH** - HP regenerative heaters, **LP** - Low Pressure unit of condensing turbine,
MP - Medium Pressure unit of condensing turbine, **RH** - LP regenerative heaters, **SC** - Steam cooler, **SI** - Steam injectors,
VC - Cooler of vapours from stuffing boxes, **WP** - Water supply pump, **WT** - Water supply tank .
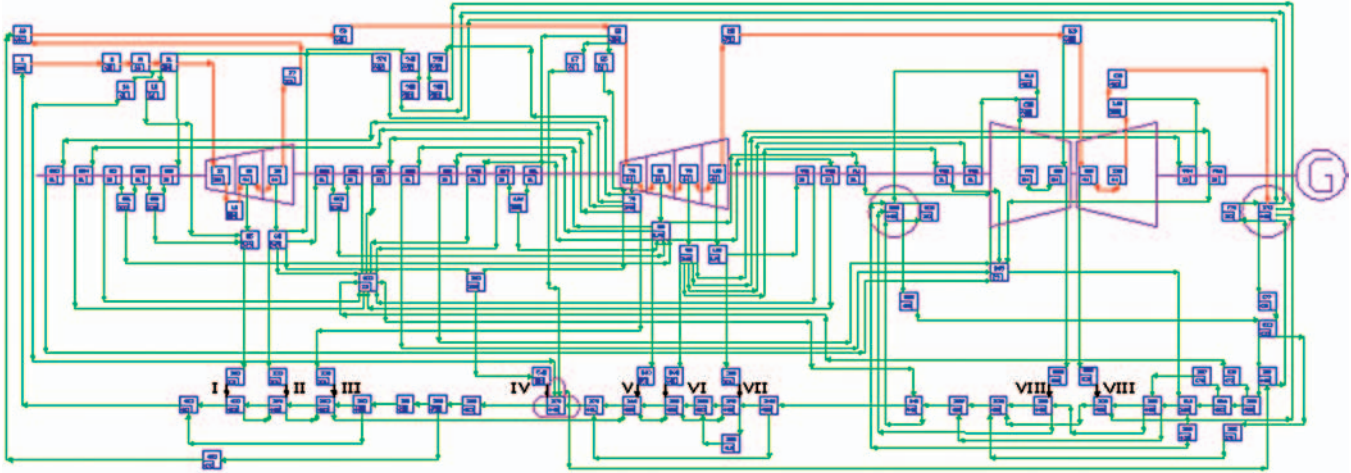

Fig. 2. Schematic computational diagram for the steam cycle considered in DIAGAR software, where :
— Main steam jet (flow)   → Steam extractions (I – VIII)   **G** - Electric generator
☐ Particular devices of the steam power unit .

Preparation of the training data set

The training data set consists of independent and dependent operational parameters of the power unit [1], namely :

Set of independent parameters :

❖ Turbine set's power output
❖ Fresh steam pressure
❖ Fresh steam temperature
❖ Superheated steam temperature
❖ Pressure in condenser,

which define loading state of the steam cycle, see Tab.1.

Set of dependent parameters :

♦ Mass flow rate (m)
♦ Pressure (p)
♦ Temperature (t)
♦ Enthalpy (h).

The heat flow parameters of working medium are determined in 176 points of the cycle. As a result the data set covered a wide range of the power unit's work, and amounted to 6300 combinations defining various loading states.

Tab. 1. Set of the parameters defining loading states of the power unit [5]
(Parameters of rated working state are marked red.) .

Set of independent operational parameters of the unit					
Power	Fresh steam pressure	Fresh steam temperature	Superheated steam temperature	Pressure in condenser	Number of combinations
N [MW]	p_o[bar]	T_1[°C]	T_2[°C]	p_k[bar]	6300
120	110	510	510	0.04	
140	120	520	520	0.05	
160	**130**	**530**	**530**	0.06	
180	140	540	540	**0.07**	
200	150	550	550	0.08	
		560	560	0.09	
				0.10	

The task consisted in training the network in order to determine a set of diagnostic (dependent) parameters in response to a given set of independent operational parameters of the power unit.

Choice of structural arrangement
of the network and algorithm of its training

During the last 20 years neural networks have been developed very dynamically. Their structures have been improved and new algorithms elaborated. However choice of optimum parameters has still remained a time-consuming process as it is realized with the use of trial-and-error method. The structures and algorithms of training the networks of which the neural simulator is consisted, were preliminarily selected on the basis of theoretical knowledge [3,4] and the published comparative analyses [3].

The most important element of the selection process was the testing of effectiveness of particular structures in solving the task in question.

Finally, the structure having two processing layers : a hidden layer of activating sigmoidal functions and an output layer of linear functions, was selected. The series of trial trainings [5] revealed that the most effective training algorithm for the task in question is that of Levenberg-Marquardt (LM). This is one of the fast convergent algorithms which not only converge after a small number of training iterations but also are much superior regarding network's response accuracy than other algorithms. However the advantages are achieved at expense of high requirements for RAM memory of used computer.
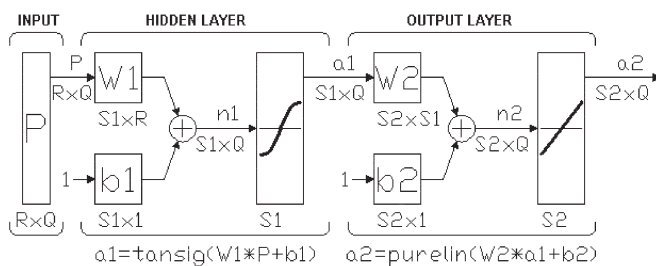

Fig. 3. Schematic diagram of the network's structure [5],
where :
a1 - *response matrix of 1st neural layer (hidden one)*
a2 - *response matrix of 2nd neural layer (network response)*
b1 - *vector of weight coefficients for 1st neural layer*
b2 - *vector of weight coefficients for 2nd neural layer*
n1 - *matrix of neurons in 1st layer*
n2 - *matrix of neurons in 2nd layer*
P - *matrix of network training images*
Q - *number of network training vectors (images), Q = 6300*
R - *training vector of 5 elements, R=5*
S1 - *number of neurons in 1st layer for each training vector (assumed value)*
S2 - *number of neurons in 2nd layer for each training vector (assumed value)*
W1 - *matrix of weight factors for 1st neural layer*
W2 - *matrix of weight factors for 2nd neural layer .*

Training process of the network

To train the one-direction network under control the error--back-propagation algorithm is usually applied. The error value determined in one iteration serves as the basis to correct weights and thresholds for the next iteration. This way a continuous improvement of network's response quality is achieved. The training terminates when response accuracy determined by comparing the response with an assumed standard, is satisfactory. However many problems have been met in practice, namely :

☆ Too small capacity of RAM memory
of the applied computer

To obtain satisfactory accuracy of the simulator a very large set of training data was required. It resulted in very large dimensions of the training matrices (5 x 6300 and 17 x 6300). The next element was a large capacity of memory demanded by the LM algorithm. A remedy for such situation was to limit the number of simulated points of the steam cycle down to those most important and to split the simulator structure into a greater number of modules.

☆ Difficulties in obtaining a satisfactory accuracy
of the network's response

The to- be- solved problem consisted in simulating distribution of parameters of a real object. Functions of the kind often have a very irregular run, with many discontinuities resulting from the character of physical phenomena occurring in the power unit, which do not represent only regular thermodynamical relationships but also many known and unknown disturbances and small irregularities. If a distribution of a given parameter was correct the network was able to be trained in generating correct responses. However in some load intervals when the irregularities were revealed (e.g. when the set values of the unit's operational parameters were very different from those at rated load) the network's responses appeared loaded by a greater error.
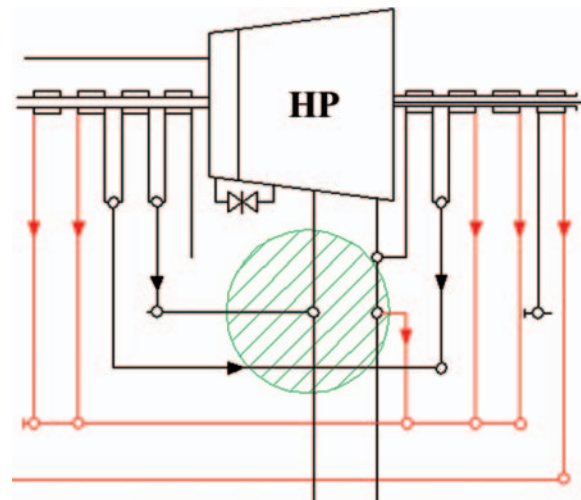

Fig. 4. Regenerative steam extraction
from the first stage of HP turbine (the shaded area) .

Such situation can be illustrated by the simulation of heat flow relationships at the first steam extraction, see Fig.4. Generally, the steam thermodynamical relationships at this point of the cycle are very complex and sensitive to many factors, that has resulted in much greater difficulties in obtaining a satisfactorily accurate response from the network. Therefore this point of the cycle has been treated in a special way : it was taken out from the remaining extractions and trained separately. The approach made it possible to vacate some capacity in RAM memory. Also, the computation time was shortened thus it was possible to increase number of training iterations. However for some loading states of the unit the network was not capable of reducing the response error, satisfactorily. As a result the obtained accuracy of the network appeared very different, see Fig.5.

☆ Necessity of application of the networks consisted
of many neurons

Complexity of the problem requires the network to be consisted of many neurons. In the cases when the network was not capable of reducing the error the number of neurons was increased. The operation usually improved abilities of the network however it was connected with some drawbacks, namely :

✦ increased loading on the processor – computation time was greater
✦ substantially increased loading on RAM memory
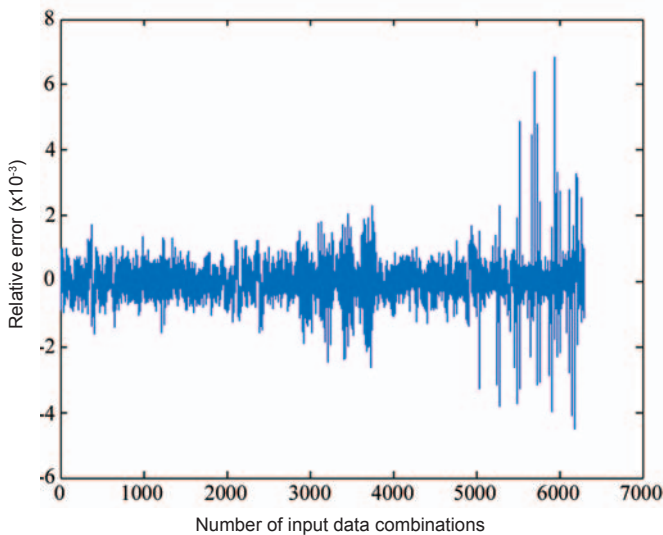✦ risk of worsening the network's capability of generalizing.

Fig. 5. *Distribution of the relative error of pressure simulation training at the first steam extraction, for the whole set of training data. The mean error : 0.04 %, the maximum error : 0.65% [5] .*

The generalizing capability of the network consists in coping with data sets not included in its training process, which is of fundamental importance for its usefulness to simulate phenomena and dependent on the number of neurons, having its optimum value.

☆ **Necessity of extending the training process**

The second method of reducing the error is the extending of training time, apart from the increasing of number of neurons. This is justified only when the reduction goes on. During training process it often has happened that the network has reduced the error very slowly though the maximum possible number of neurons (with respect to RAM memory capacity) was applied. Then the only way to improve accuracy of the network's response was to increase number of iterations that extended training time.

Summing up one can state that in the case in question the capabilities of the used hardware (a typical personal computer) were of decisive importance; however they did not substantially influence the quality of the elaborated simulator though an additional time outlay was necessary.

FEATURES OF THE SIMULATOR

The simulator was composed of 12 neural networks. Each of them was separately optimized. Due to the hardware limitations it was necessary to split all the simulated points of the steam cycle into 3 groups (modules), see Fig.2 and 6.

♦ The main steam jet contains the points 1 through 21 located between the boiler and condenser including the flow part of the turbines.

♦ The first steam extension is in the point 22 where 3 steam jets are mixed together : the regenerative steam extension from the first stage of the turbine, the steam from the sealing of HP turbine casing and that from the sealing of control valves.

♦ The remaining extensions (points 23 through 30) are located in the remaining steam extension pipelines leading to relevant regeneration heat exchangers.

Fig.6 illustrates the procedure of information flow during the simulation process. Each of the networks operates separately and provides only one parameter and only within a given group of the cycle's points. In all the 30 points the distribution of 4 parameters, i.e. p, m, t, h, can be simulated, or an arbitrary module and a parameter can be selected to obtain the pressure parameters from p1 to p21. The user can also select one of the simulated cycle's points to know a concrete parameter value.
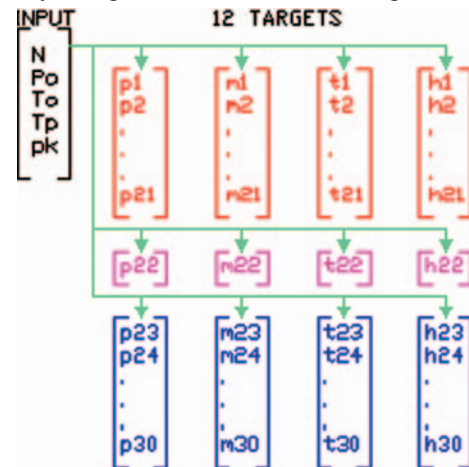

Fig. 6. *Schematic diagram of the simulator's modular structure [6], where :*
h - *enthalpy in a given point of cycle [kJ/kg] (resultant)*
h1 - h21 - *enthalpy put out by 1st module of simulator : main flow*
h22 - *enthalpy put out by 2nd module of simulator : 1st regenerative steam extraction*
h23 - h30 - *enthalpy put out by 3rd module of simulator : remaining regenerative steam extractions*
m - *mass steam flow rate in a given point of cycle [kg/s] (resultant)*
m1 - m21 - *mass steam flow rate put out by 1st module of simulator : main flow*
m22 - *mass steam flow rate put out by 2nd module of simulator : 1st regenerative steam extraction*
m23 - m30 - *mass steam flow rate put out by 3rd module of simulator : remaining regenerative steam extraction*
N - *assumed output of steam power unit [kW]*
p - *pressure in a given point of cycle [bar] (resultant)*
p1 - p21 - *pressure put out by 1st module of simulator : main flow*
p22 - *pressure put out by 2nd module of simulator : 1st regenerative steam extraction*
p23 - p30 - *pressure put out by 3rd module of simulator : remaining regenerative steam extractions*
pk - *assumed value of pressure within condenser [bar]*
Po - *assumed value of fresh steam pressure [bar]*
t - *temperature in a given point of cycle [°C] (resultant)*
t1 - t21 - *temperature put out by 1st module of simulator : main flow*
t22 - *temperature put out by 2nd module of simulator : 1st regenerative steam extraction*
t23 - t30 - *temperature put out by 3rd module of simulator : remaining regenerative steam extractions*
To - *assumed value of fresh steam temperature [°C]*
Tp - *assumed value of superheated steam temperature [°C] .*

CONTROL OF OPERATIONAL ACCURACY OF THE SIMULATOR

Great attention was paid to continuous control of operation of the neural networks as they represent rather primitive algorithms (not including any interpretation of physical phenomena). Also, much work was done to reliably present the simulator's accuracy, especially as it appeared to be very different, depending on a concrete cycle's point, simulated parameter and assumed state of loading.

Fig.7 presents distribution of values of the relative error of mass flow simulation for the main steam jet and all combinations of training data.

During simulation of the parameters an error value is automatically displayed provided its precise determination is possible at all. If a set of load parameters does not belong to that of training data then an expected value of the error is given.

A more precise verification of operational quality of the simulator was performed by using the DIAGAR analytical simulator since its responses could be taken as a standard for

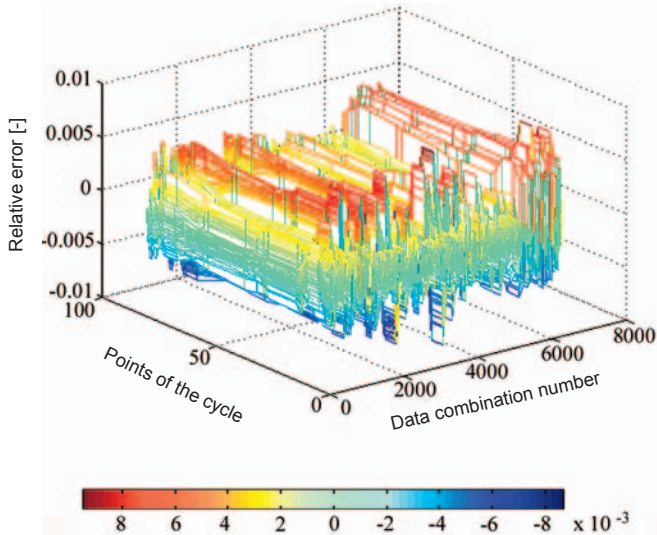*Area of relative error of mass simulation training for the main steam jet, 20 neurons, 100 iterations .*

Fig. 7. *Distribution of simulation error of enthalpy parameter for the main steam jet (21 points of the cycle) [5] .*

the neural simulator. This way at the expense of some additional efforts response uncertainty of the network could be reduced to a minimum. Such operation was performed for the first steam extraction and due to its specificity an additional set of testing data was taken from the DIAGAR and on its basis the network's generalization accuracy was determined for this module. In Fig.8 is presented an example of the results of the above described operation for distribution of mass flow rate at the first steam extraction. A testing data set not contained in the training data but belonging to the same loading range, was put into the network.

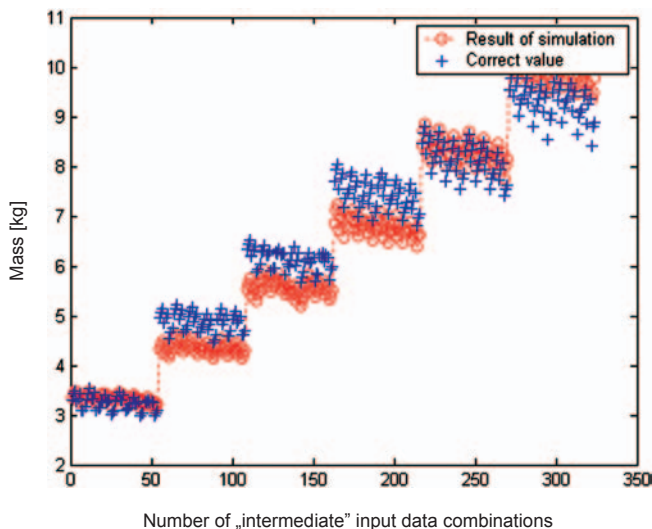*Generalization testing results for NI97M network .*

Fig. 8. *Results of testing the network's generalization capability for mass flow rate at the first steam extraction .*

SUMMARY

❖ The neural simulator of the steam power unit was elaborated to investigate possibility of its application to an on-line diagnostic system for so complex objects as steam turbine power plants are.

❖ The presented simulator is a tool of the following features :
  ⇨ simple in use
  ⇨ fast in operation : determination time of one parameter in 30 points of the cycle amounts to 30 ms
  ⇨ sufficiently exact
  ⇨ inexpensive : to its manufacturing only a set of operational parameters of a considered object, MATLAB software and a typical personal computer is required.

❖ On the basis of the performed task were also analyzed some practical aspects of the neural modeling method, constituting its merits and drawbacks related to the considered application. The most important merit is the possibility of omitting the long analytical modeling process, hence lowering the modeling cost; and, the most important drawback is that the neural model does not include any physical interpretation of phenomena.

❖ Modelling by means of neural networks is realized on the basis of existing operational or statistical data. In the case when character of a phenomenon is complex and multidimensional, and first of all not quite recognized, as well as when availability of the data is high, then such conditions can be taken as very favourable for neural modelling. In some cases the method is the most suitable, and sometimes the only possible. In other cases it can be useful as an aiding element for analytical models.

❖ The tasks assigned to advanced diagnostic systems applicable to large technical systems make that so different approaches as analytical methods, hidden ones (neural networks) or fuzzy logic, are used for them. Their mutual interaction is often very favourable for accuracy and credibility of an obtained result, i.e. assessed technical state of an object.

BIBLIOGRAPHY

1. Głuch J. : *Verification of selected experimental coefficients of turbine flow design process , based on standard measurements of power units* (in Polish). Doctorate thesis. Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology. Gdańsk, 1992
2. Gardzielewicz A., Głuch J., Uziębło W., Jankowski T.: *DIAGAR software for heat flow diagnostics as a tool to predict repair time for component devices of turbine power systems.* (in Polish). Proceedings of 5th Domestic Scientific Technical Conference on Diagnostics of Industrial Processes. Łagów Lubuski. September 2001
3. Korbicz J., Obuchowicz A., Uciński D. : *Artificial neural networks* (in Polish). Academic Publishing House (PLJ). Warszawa, 1994
4. Demuth H., Beale M.: *Neural Network Toolbox.* 2001
5. Ślęzak-Żołna J.: *Neural simulator of a steam power unit* (in Polish). M.Sc. thesis. Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology. Gdańsk, 2004
6. Ślęzak-Żołna J., Głuch J.: *Neural simulator of a steam power unit* (in Polish). Proceedings of the Conference on Technical, Economical and Environmental Aspects of Combined Steam Systems. Gdańsk, 2004 .

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Noise and Vibration

On 8-12 June 2005 at Wigry, a touristic and rest resort in north-east Poland, was held 7th Conference on :

### *Active Noise and Vibration Control Methods*

It was organized by Faculty of Mechanical Engineering and Robotics, Mining and Metallurgy Academy of Cracow. The Conference's program contained 56 papers prepared by the authors representing 19 Polish universities and scientific research centres, as well as those of Czech Republic, Finland, France, Lithuania, Slovakia and USA. The greatest contribution (20 papers) gave scientific workers of the host university which first in Poland initiated research on active vibration and noise control.

Presentation of the papers was carried out during 8 sessions, namely :

⇨ *Plenary session* (4 papers)
⇨ *Active vibration control* (18 papers)
⇨ *Active noise control* (7 papers)
⇨ *Semi-active control* (3 papers)
⇨ *Structural control* (2 papers)
⇨ *Hardware and software for active noise and vibration control* (4 papers)
⇨ *Vibration isolation* (4 papers)
⇨ *Smart materials for adaptive vibration control* (14 papers).

Polish sea-coast scientific circle was represented by 4 research centres which presented the following papers :

➲ *Diagnosing the elements of propulsion plant of naval vessels by means of vibration measurement* – by A. Charchalis, R. Cwilewicz (Gdynia Maritime University) and A. Grządziela (Polish Naval University)

➲ *Vibration surveillance in high-speed milling machines by the spindle speed control* – by K. Kaliński (Gdańsk University of Technology)

➲ *Vibration surveillance in the hybrid system by optimum control of energy performance index - on example of milling flexible details* – by K. Kaliński (Gdańsk University of Technology)

➲ *Crack indicators for large power turbo-set monitoring and diagnostic system* – by J. Kiciński and S. Banaszek (The Szewalski Insitute of Fluid-Flow Machinery, Polish Academy of Sciences, Gdańsk) .
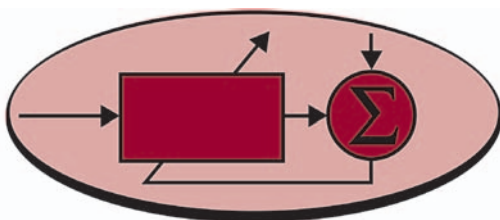
Automation

On 27-30 June 2005 in Warsaw was held 15th Domestic Conference on Automation, organized by Committee on Automation and Robotics, and System Research Institute of Polish Academy of Sciences, and hosted by Warsaw University of Technology and Industrial Institute of Automation and Measurements.

The Conference's program contained 196 papers including 6 plenary ones; the rest of them were presented during 16 topical sessions. The session on *Technical applications* was the most popular among authors who submitted to it as many as 40 papers. 13 papers were devoted strictly to marine engineering problems, namely :

☆ *Ship automation systems and CAD methods for them* by Z. Kowalski and M. Drewka (Gdańsk University of Technology)
☆ *Application of mathematical models in designing thrusters and electric propulsion systems for ships* – by R. Arendt, A. Kopczyński and M.Wojtczak (Gdańsk University of Technology)
☆ *Structure and selected procedures of a knowledge--based system for designing automation of energy subsystems on ships* – by R. Arendt, M. Kostrzewski, Z. Kowalski and E. Van Unden (Gdańsk University of Technology)
☆ *An algorithm of ship course stabilization based on a computer model of ship dynamics* – by P. Borkowski (Technical University of Szczecin), Z. Zwierzewicz (Maritime University of Szczecin)
☆ *Precise ship control by means of multi-dimensional though controllers* – by W. Gierusz (Gdynia Maritime University)
☆ *A system for safe optimum control of ship at sea* by A. Łebkowski, R. Śmierzchalski, M. Tobiasz, K. Dziedzicki, M. Tomera (Gdynia Maritime University)
☆ *Modelling the dangerous and weather areas in ship's routing process* – by A. Łebkowski, R. Śmierzchalski, M. Tomera (Gdynia Maritime University)
☆ *Simulation of ship precise motion* – by J. Małecki (Polish Naval University)
☆ *Problems of automation of ship's electric energy systems* – by R. Śmierzchalski (Gdynia Maritime University)
☆ *Ship trajectory controller in the aspect of ship steering in a collision situation* – by M. Tobiasz, M. Tomera, A. Łebkowski, K. Dziedzicki, R. Śmierzchalski (Gdynia Maritime University)
☆ *Application of back-stepping method to ship motion control* - by A. Witkowska (Gdańsk University of Technology), M. Tomera, R. Śmierzchalski (Gdynia Maritime University)
☆ *Assessment of capability of underwater robot to generate set-up control outputs* – by J. Garus (Polish Naval University)
☆ *Modelling dynamic behaviour of underwater robots* by A. Żak (Polish Naval University) .

Approximation of pitching motion of S-175 containership in irregular waves on the basis of ship's service parameters

Tomasz Cepowski
Maritime University of Szczecin

ABSTRACT

This paper presents approximations of pitching motion of S-175 containership in irregular waves within the full range of ship's service parameters. It continues the research described in [1] dealing with application of artificial neural networks to predict ship's motions. Reference pitch values were calculated by means of SEAWAY software based on accurate numerical methods. Approximating function was elaborated by using the artificial neural networks.

Keywords : seakeeping qualities, pitching, artificial neural networks, approximation, ship service parameters, irregular waves

INTRODUCTION

In the paper [1] were presented approximations of ship roll in regular and irregular waves, obtained on the basis of ship service parameters and wave parameters. Such approximations may find application a.o. in ship voyage routing problems as well as in controlling ship seakeeping ability during its service. From the there presented considerations it results that to approximate ship's roll statistical methods and artificial neural networks can be applied, and, the highest approximation accuracy, both within and outside the assumed range of input parameters, was obtained by applying the functions elaborated by means of artificial neural networks.

In this paper a continuation of the above mentioned research was presented. It was aimed at checking if artificial neural networks may be used to approximate another ship motion, namely pitching. Taking into account that in [1] the best results were obtained for ship's roll in irregular waves in this research the author decided to approximate ship pitching motion in irregular waves only. Additionally, the pitch approximations were expanded onto the full range of wave encounter angles.

SIGNIFICANT PITCH AMPLITUDES OF THE SHIP

To approximate the ship's pitching the method presented in [1,6] was applied. The reference data were determined by using SEAWAY software. In Fig.1 and 2 are presented the pitch transfer functions calculated by means of the SEAWAY, in comparison with experimental results; from the comparison it can be concluded that the SEAWAY provides sufficiently accurate results for the kind of ship motions in question.
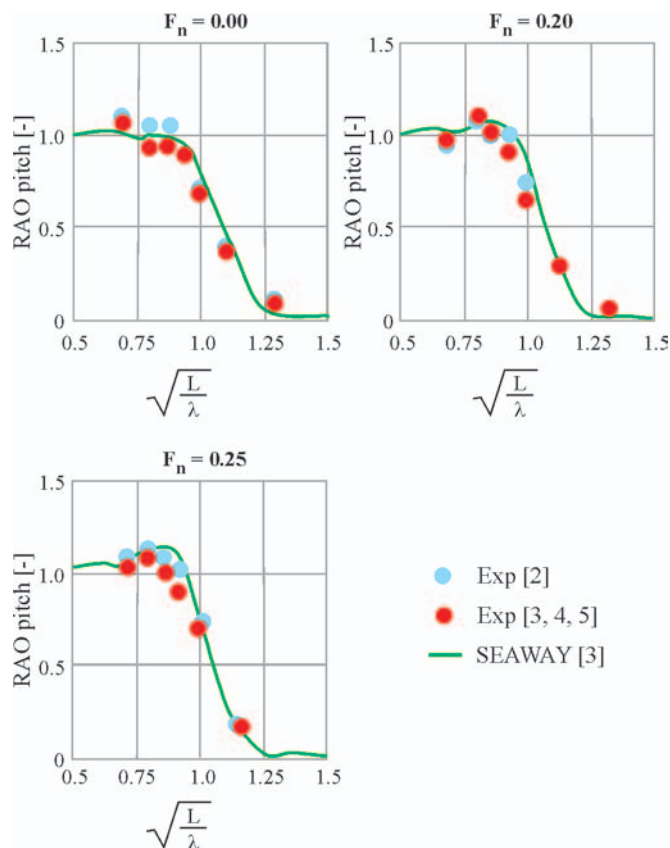

Fig. 1. *Pitch amplitudes of the fast cargo ship „S.A. van der Stel'' of L = 152.5 m , B = 22.80 m , d = 9.14 m , C_B = 0.563 , Z_G = 9.14 m , sailing in heading waves, acc. [2,3,4,5] .*
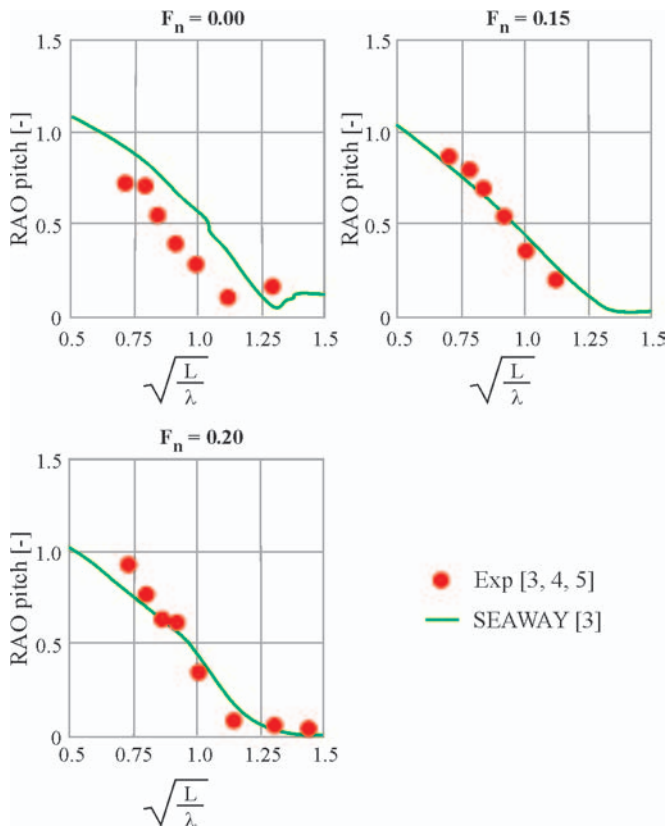
Fig. 2. Pitch amplitudes of the fast cargo ship „S.A. van der Stel"
of $L = 152.5\ m$, $B = 22.80\ m$, $d = 9.14\ m$, $C_B = 0.563$, $Z_G = 9.14\ m$,
sailing in following waves, acc. [3,4,5].

Calculations of the significant pitch $\psi_{1/3}$ were performed, similarly as in [1], for the example S-175 containership of the following main dimensions :

length between perpendiculars : L = 175 m
breadth : B = 25.4 m
design draught : d = 9.5 m.

The following ranges of ship service parameters
and wave parameters were taken into account :

- ship's speed V : from 0 to 20 kn, at every 5 kn
- ship's draught d : from 5 m to 11 m, at every 2 m
- wave encounter angle $\beta = 0°$ (head wave), 10, 20, 30, 60, 90, 120, 150, 160, 170, 180° (following wave)
- significant wave height Hs : from 2 m to 5 m, at every 1 m
- characteristic wave period T : from 6.5 s to 14.5 s, at every 2 s.

As a result of the calculations was obtained the data set containing 4400 records which was further used to elaborate pitch approximations. In Fig.3 through 6 are presented selected
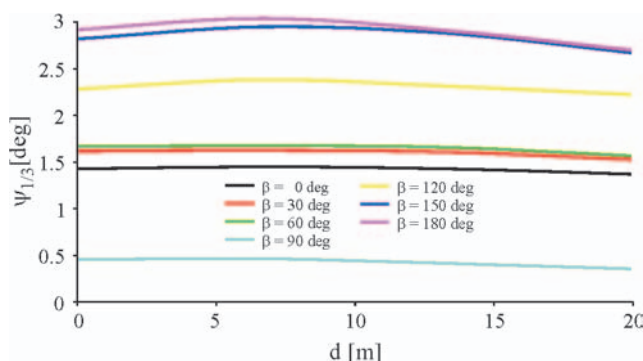
Fig. 3. Significant pitch amplitudes $\psi_{1/3}$ for S-175 containership,
d = var , β = var , V = 20 kn , Hs= 5 m , T = 10.5 s .

relationships between the pitch amplitudes calculated this way, ship service parameters and wave parameters, in different combinations.
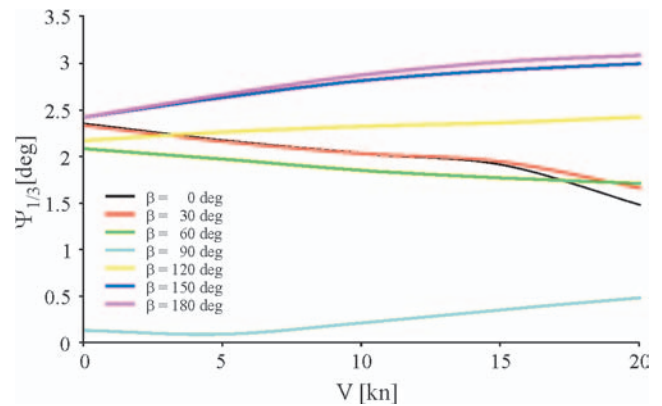
Fig. 4. Significant pitch amplitudes $\psi_{1/3}$ for S-175 containership,
V = var , β = var , d = 7 m , Hs = 5 m , T = 10.5 s .
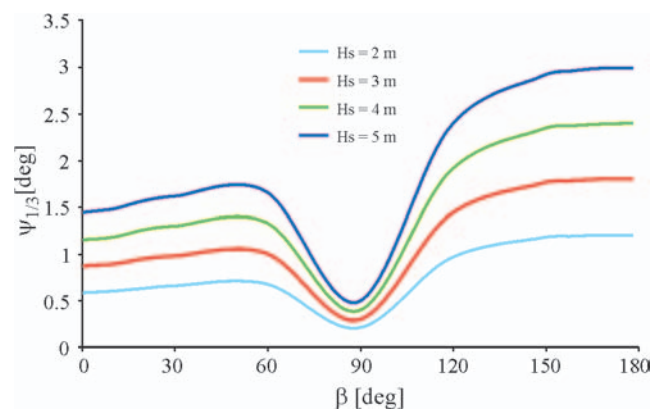
Fig. 5. Significant pitch amplitudes $\psi_{1/3}$ for S-175 containership,
β = var , Hs = var , d = 7 m , V= 20 kn , T = 10.5 s .
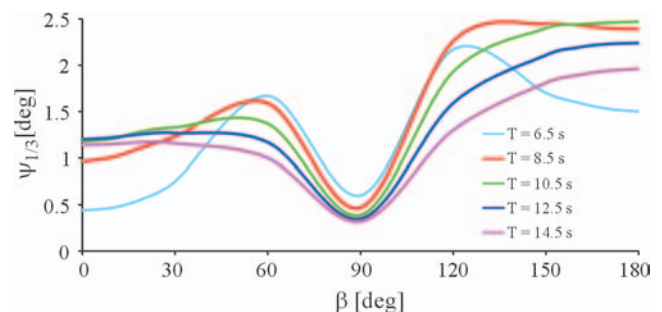
Fig. 6. Significant pitch amplitudes $\psi_{1/3}$ for S-175 containership,
β = var , T = var , d = 7 m , V= 20 kn , Hs = 5 m .

PITCH APPROXIMATION BY MEANS OF ARTIFICIAL NEURAL NETWORKS

In accordance with [1] the function approximating the significant pitch amplitudes $\psi_{1/3}$ can be determined by using the following formula:

$$X \xrightarrow{\ \Psi_{1/3}\ } Y \tag{1}$$

where :

X   – set of assumed ship service parameters (input)
Y   – set of values of significant pitch amplitudes (output) calculated by using exact methods
$\psi_{1/3}$ – searched function approximating the significant pitch amplitudes.

It was assumed that the pitch approximations
had to be elaborated for the following parameters :

☆ ship draught d
☆ ship speed V
☆ wave encounter angle β
☆ significant wave height Hs
☆ characteristic wave period T.

For determining a function approximating the pitch amplitudes $\psi_{1/3}$ the artificial neural networks were applied. In this research the following types of them were tested :

❖ Multilayer Perceptron (MLP)
  of a sigmoidal activation function
❖ Generalized Regression Neural Network
  (GRNN) – a regression network
❖ Radial Basic Function Network (RBF).

The phase of searching for the most appropriate
network contained the following steps :

➢ description of the best network structure by means
  of genetic algorithms
➢ learning a network (usually by using the back-pro-
  pagation method)
➢ testing a network
➢ assessment of approximation accuracy obtainable
  within a network on the basis of the testing data.

To validate and test the networks the set containing 50 % amount of the variants deleted by sampling from the learning data set.

The MLP network of the structure : 5 (inputs) x 7 (hidden neurons) x 1 (output), appeared the most accurate (Fig.7), being characterized by:

✦ the smallest learning RMS error = 0.12°
✦ the smallest testing   RMS error = 0.13°

Values of RMS error were calculated
from the formula (2) :

$$RMS = \sqrt{\frac{(\Psi_w - \Psi_{1/3})^2}{n}} \qquad (2)$$

where :

ψ_w – reference values of significant pitch amplitudes
     used for learning or testing a neural network
$\psi_{1/3}$ – approximated significant pitch amplitudes
n   – number of records.

The calculations were carried out by using
the package STATISTICA Neural Networks.

The searched function approximating the significant pitch amplitudes $\psi_{1/3}$ elaborated by means of the above mentioned neural network was represented analytically with the use of the equation (3):

$$\Psi_{1/3} = \frac{\left(\dfrac{1}{1+e^{-([d,V,\beta,Hs,T]\cdot S+P)\cdot A - B)}} \cdot C - \alpha_0\right) - \alpha_1}{\alpha_2} \qquad (3)$$

where :

d   – ship draught [m]
Hs – significant wave height [m]
T   – characteristic wave period [s]
V   – ship speed [kn]
β   – wave encounter angle [deg]
$\psi_{1/3}$ – significant pitch amplitude [deg].

A – matrix of weighting factors :

$$\begin{bmatrix} 0.320 & -0.082 & 0.111 & 0.059 & 0.253 & -0.348 & 3.170 \\ 0.265 & -0.193 & 1.283 & 0.182 & 0.332 & 0.033 & 0.291 \\ 3.872 & 16.732 & -2.413 & -20.422 & -0.447 & -3.375 & -1.039 \\ 0.390 & 1.056 & 0.831 & -0.944 & -1.138 & -0.124 & 0.133 \\ -3.097 & -0.575 & -4.895 & 0.620 & 0.655 & 2.671 & 0.647 \end{bmatrix}$$

B – vector of threshold values :

[2.58 9.69 2.75 -12.15 -0.46 -2.61 -2.10]

C – vector of weighting factor values :

2.9538
-4.5864
-1.8491
-4.5384
-1.3287
3.7736
0.7011

S – matrix of coefficients :

$$\begin{bmatrix} 0.01667 & 0 & 0 & 0 & 0 \\ 0 & 0.0500 & 0 & 0 & 0 \\ 0 & 0 & 0.0056 & 0 & 0 \\ 0 & 0 & 0 & 0.3333 & 0 \\ 0 & 0 & 0 & 0 & 0.1250 \end{bmatrix}$$

P – vector of shift values :

[-0.83333 0 0 -0.667 -0.8125]

α_0, α_1, α_2 – coefficients having the values :

$\alpha_0 = -1.37$ $\alpha_1 = -0.0065$ $\alpha_2 = 0.3268$
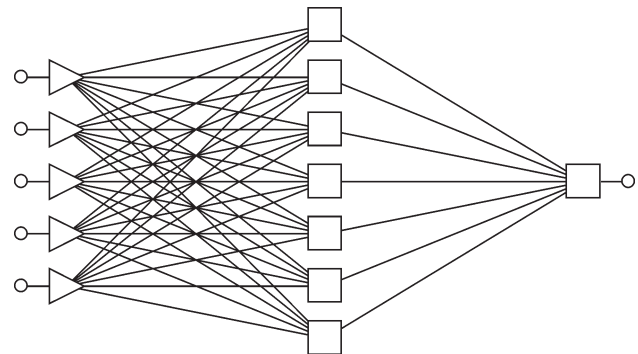
Fig. 7. Structure of the artificial neural
network approximating pitch amplitudes .

Sensitivity analysis of the elaborated neural network showed that all input parameters have been important, at the following decreasing significance :

★ the wave encounter angle β
★ the significant wave height Hs
★ the characteristic wave period T
★ the ship draught d
★ the ship speed V.

In Fig.8 through 10 is presented the comparison of the pitch approximations calculated by applying Eq. (3) with the values calculated by using the exact methods included in the SEAWAY software. The there presented data were not used for modelling the neural network. From the diagrams it results that the function approximating the pitch amplitudes described by Eq. (3) is very exact and shows the same trends as the data.
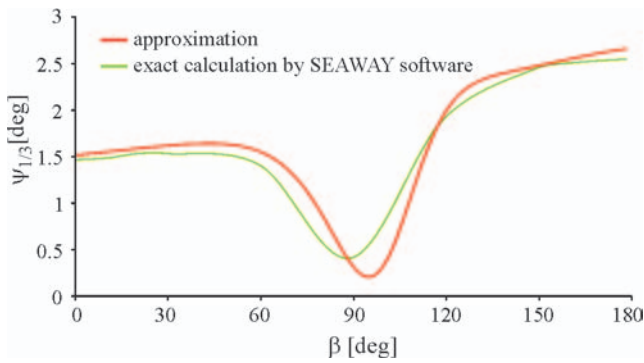
Fig. 8. The approximations of significant pitch amplitudes, compared with the testing values, for : β = var , V = 20 kn , T = 12.5 s , Hs = 5 m , d = 11 m .
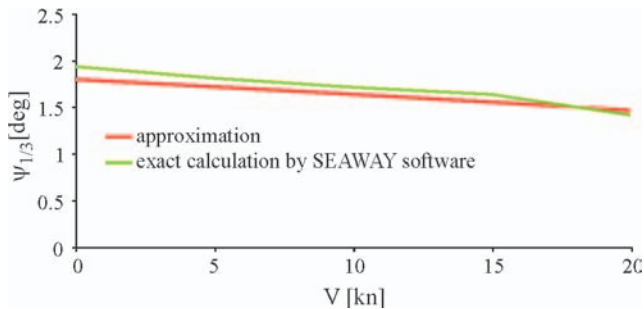
Fig. 9. The approximations of significant pitch amplitude, compared with the testing values, for : V = var , β = 0 deg , T = 12.5 s , Hs = 5 m , d = 11 m .
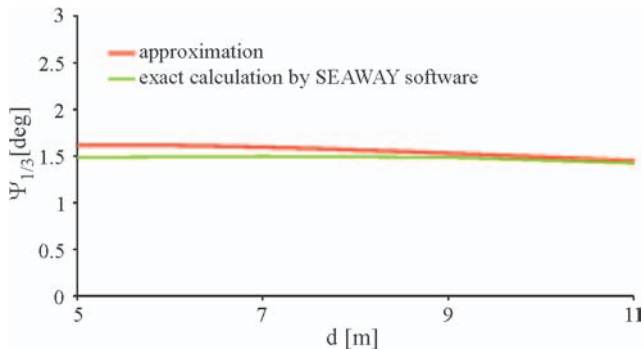
Fig.10. The approximations of significant pitch amplitudes, compared with the testing values, for : d = var , β = 0 deg , T = 12.5 s , Hs = 5 m , V = 20 kn .

RECAPITULATION

❍ In this paper are presented the approximations of pitch amplitudes, based on the following ship service parameters :

⇒ ship speed
⇒ ship draught
⇒ wave encounter angle,

and the wave parameters :

➢ significant wave height
➢ characteristic wave period,

considered within a broad range of the above specified parameters.

❍ The pitch amplitude approximating function was elaborated with the use of artificial neural networks and presented in the analytical form. The function is highly accurate as compared with the testing data calculated by means of the exact methods.

❍ The reference pitch amplitude values were calculated by using exact numerical methods. On the assumption that the values do not significantly differ from real ship's pitching data, the presented approach can be applied to predict ship's pitch on the basis of the data recorded on board the ship.

❍ The obtained research results confirm that the artificial neural networks can be applied to approximate such ship response as pitch and roll (presented in [1]) both in the phase of ship's design and operation. [1].

NOMENCLATURE

B – ship breadth
C_B – ship block coefficient
d – ship draught
F_n – Freude Number
GM – initial transverse metacentric height
Hs – significant wave height
L – ship length between perpendiculars
RAO – Response Amplitude Operator
T – characteristic wave period
V – ship speed
Z_G – height of ship centre of gravity
β – wave encounter angle
λ – wave length
$\psi_{1/3}$ – approximated significant pitch amplitude
ψ_w – reference significant pitch amplitude

BIBLIOGRAPHY

1. Cepowski T. *Application of statistical method and artificial neural networks for approximating ship's roll in beam waves*. Polish Maritime Research, No. 2, April 2005
2. Gerritsma, J. and Beukelman, W.: *Analysis of the Resistance Increase in Waves of a Fast Cargo-ship*. International Shipbuilding Progress, 18(217), 1972
3. Journée J.M.J. *Verification and Validation of Ship Motions Program SEAWAY*. Report1213a, Delft University of Technology, The Netherlands. 2001
4. Journée, J. M. J.: *Motions and Resistance of a Ship in Regular Following Waves*. Technical Report 440, Delft University of Technology, Ship Hydromechanics Laboratory, The Netherlands. (internet: http://dutw189.wbmt.tudelft.nl/~johan or http://www.shipmotions.nl). 1976
5. Journée, J. M. J.: *Motions, Resistance and Propulsion of a Ship in Longitudinal Regular Waves*. Technical Report 428, Delft University of Technology, Ship Hydromechanics Laboratory, The Netherlands. (internet: http://dutw189.wbmt.tudelft.nl/~johan or http://www.shipmotions.nl). 1976
6. Staszewska K., Cepowski T.: *Prediction of ship's roll by means of artificial neural networks* (in Polish), Scientific bulletins of Szczecin Maritime University (Zeszyty Naukowe AM) No. 74. Szczecin, 2004
7. Szelangiewicz T., Cepowski T.: *Application of artificial neural networks to investigation of ship seakeeping ability*, Part 1, Polish Maritime Research, Vol 8, No. 3, September 2001 .

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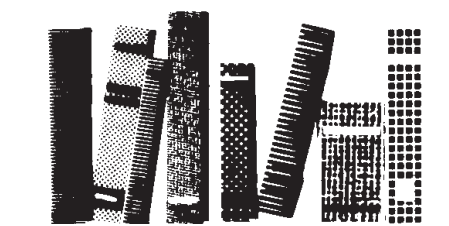
Assessment of the safety level of a ships' passing manoeuvre in the fairway

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ABSTRACT

Safe two-way vessel traffic may have some limitations. Fairway width, vessel dimensions, weather conditions, traffic density and other factors must be considered crucial and constraining safe passage of the vessel. The possible sea traffic regulation made by a Vessel Traffic Service (VTS) shore centre, is often based on criteria included in harbour regulations. This may not always be an optimum solution. This paper presents a concept and elements of a method for assessment of safe two-way traffic, based on experts' (pilots') knowledge and experience. The goal is to support the decision making process in a VTS centre. For this purpose tools of knowledge acquisition and representation as well as tools of statistical inference are used. The method is based on the results of the expert research which was performed with the participation of pilots who handle vessels on the Świnoujście-Szczecin fairway.

Keywords : safety of navigation, Vessels Traffic Service (VTS)

INTRODUCTION

Ensuring adequate technical parameters of port waterways as well as the development and modernisation of the port infrastructure are the main issues related to the safety of maritime transport. Although fairway parameters such as depths and widths, different for each port, affect its safety and efficiency, management of waterways is equally important. Safe and effective port waterways management depends on traffic density information and actual meteorological and hydrological conditions.

Improvements in the safety of ports and waterways are necessary for several reasons including demands of growing international trade, the trend toward larger ships and faster loading and unloading operations, the presence of oil and hazardous cargo in congested and heavily populated areas and concerns about maritime accidents that may cause environmental damage. These improvements can be realised through investments both into traditional aids of navigation (beacons, buoys, lights) and advanced maritime information systems like real-time information on weather conditions, pilotage navigation systems and decision support systems for a VTS Centre.

Although the term „Vessel Traffic Service" was internationally used for the first time in the 1970s, systems supporting vessel traffic control were established much earlier [11]. First local initiatives were taken just after the Second World War. Liverpool was the first port in the world to receive (in 1948) a monitoring station and radio equipment. Over the next fifty years such services were introduced by port authorities and coastal state administrations and at present more than 250 such systems ensure regular control in port areas, port approaches and narrow traffic lanes [3].

The VTS idea is based on establishing services for ships' traffic safety and efficiency improvement. The scope of tasks may vary from simple information exchange in ship-land communications to traffic management, i.e. planning such vessels' routes and passages which minimise risk of collision. The assessment of collision risk is based on the information on actual meteorological and hydrological conditions, traffic density, available aids of navigation and technical infrastructure [5].

The creation of VTS systems made it is necessary to define rights, obligations and responsibilities of shore-based centres, vessel masters and pilots. A VTS, with its specialised knowledge of a given waterway is responsible for traffic management in the area. On the other hand, the master, with his knowledge of vessel behaviour and professional skills, is responsible for the safety of the vessel. With taking into account the different- but related - responsibilities, all instructions from the shore centre to the vessel must be result-oriented, while the details of their execution fall on the master and pilot.

KNOWLEDGE ACQUISITION AND REPRESENTATION

Knowledge acquisition can be defined as a formalised, heuristic process of gathering information, data or explanations concerning the domain of relevant knowledge [2]. Experts are the main source of such knowledge. They cannot be usually omitted in the knowledge acquisition process.

The effectiveness of expert system is determined by the process of knowledge acquisition. In this process, the articulation of knowledge is a topic of great importance. In the

presented research the method of knowledge acquisition based on examples was used. This is a method of inductive nature, in which a general model is constructed by using induction rules and is based on a set of examples [9].

Experts' questionnaires are one of the most popular heuristic methods of knowledge acquisition. The independence of experts opinion and the anonymity of judgements made by experts working in isolation are distinctive features of this method. The anonymity ensured during the research allows an expert to express an opinion which is not in conformity with the most common one.

The terms „expert" and „expert opinion" do not have a uniform interpretation. For instance, an expert can be considered as a person invited to take part in the research because of his or her knowledge, personality, professional experience etc [4].

An expert can be defined as a very skilful person who has had much training and has knowledge in a specific field. This expert is the provider of an opinion in the process of expert's opinion elicitation. An expert opinion can be defined as a formal judgement of an expert on a matter in which his or her advice is sought. Such opinion is a subjective assessment, evaluation, impression or estimation of the quality or quantity of something of interest that seems true, valid or probable to the experts' own mind [2].

The research subject described in this paper is the part of specific expert's knowledge learned in the training process. It consists of all the particular heuristics and shortcuts that a trained professional has learned to use in order to perform better. His or her practice is anchored in the theory which is also needed but could be only the base [6].

The term „knowledge representation" could be used to define the formalised process of transferring, writing and gathering the knowledge meant as a description of surrounding world, consisting of facts and relations. Such knowledge representation must provide a proper structure of description and interpretation. The process has to be formalised when experts' knowledge is to be used in a decision support system.

There is no one, universal, widely accepted way of knowledge representation. Methods of representation must take into consideration a variety of knowledge elements. However future application is also very important. There are only some features that can be required, namely : transparency, accuracy, efficacy, neutrality and adequacy [12].

Some authors use the term „uncertain knowledge representation" for the definition of methods of inference used in decision support systems. Those authors define uncertainty as a lack of information needed for decision making. Sources of uncertainty are : inaccuracy of measuring methods, the existence of parameters omitted as well as the lack of proper experts' knowledge [7].

To define means of interpretation of accepted uncertainty measures is a difficult and important task. The use of probability calculus is one admissible solution. Probability is commonly accepted as a quantitative measure of uncertainty both for premises and for rules of inference.

Statistical methods of analysis (descriptive and inference) are a very useful tool in the perception of structure, interdependence and dynamics of a phenomenon [8]. These methods range from simple explanatory data analysis and significance testing to highly complicated mathematical modelling techniques. Some of them help to summarise efficiently large amount of data while the others help to understand the effects of a number of variables on another variable of interest. One should always remember that statistical inference belongs, besides inference by analogy, to the group of probabilistic inferences, which means that on the basis of true premises we can come to false conclusions [13].

PRINCIPLES OF THE METHOD

The presented method was based
on the following principles :

❖ Safety level is the quantitative feature of each manoeuvre. It depends on many factors but mainly on: manoeuvring area parameters, vessel's parameters, executed manoeuvre parameters, and those of actual hydrological and meteorological conditions.

❖ Safety level index is the quantitative measure of the safety level.

❖ Safety level can be rated by an expert (pilot) because of his or her knowledge and professional experience. The experts' knowledge can be gained by using expert's questionnaires.

❖ The questionnaire used in this research was built on the following principles :

✦ The questionnaire contains an expert's opinion which is a subjective assessment (evaluation) that seems true and valid to the expert's own mind.

✦ The expert's opinion expressed by the figure ranging from „1" (safe manoeuvre) to „10" (unsafe manoeuvre), is the quantitative measure of the safety level of ships' passing manoeuvre.

❖ Evaluation of the safety level made by experts is based on specific expert's knowledge learned in the training process in order to perform better.

INVESTIGATIONS

The expert research (by using questionnaires) was performed with the participation of pilots handling vessels on the Świnoujście-Szczecin fairway. It aimed at answering two main questions:

➲ Is the safety level of manoeuvres of two vessels passing each other affected only by their main dimensions or by actual hydrological and meteorological conditions as well ?

➲ Is the safety level of manoeuvres of two vessels passing each other affected also by the section of the fairway in which the manoeuvre is executed? (i.e. are there sections on the fairway where manoeuvre execution is safer not only due to the canal width).

The safety level was based on pilot's assessment with the use of 10-degree scale. Only the vessels frequently calling at port of Szczecin were taken into consideration.

One of the main tasks of the research was to determine the influence of vessels' dimensions and hydrological and meteorological conditions on safety level (pilots' assessment). Nine following factors (independent variables) were assumed :

✶ length, width and draught of the vessel entering the port
✶ length, width and draught of the vessel leaving the port
✶ visibility
✶ wind force
✶ time of day (daylight or night).

The factor not taken into consideration was a kind (dangerous / non-dangerous) of the cargo on board. The results of previously performed studies show a very low priority of this factor for pilots. This factor must of course be implemented in harbour regulations but its influence on pilot's assessment cannot be considered significant. Pilots' opinion in this mat-

ter may also be affected by his or her professional experience (e.g. gained in handling oil and/or chemical tankers) [10]. The research task was to find out if the influence of all above mentioned factors is equal in all fairway sections.

According to the Regulation of Ministry of Infrastructure [14] Świnoujście-Szczecin waterway should have the width of 90 m with the depth of 10.5 m (with the exception of a part of the port of Świnoujście and one branch of the waterway near the port of Police where the required width is 150 m). It is not, however, a uniform waterway. It consists of canals, dredged stretches of rivers (Odra, Świna) and the Gulf of Szczecin. For the purpose of this research the waterway was divided into 11 sections shown in Fig.1.
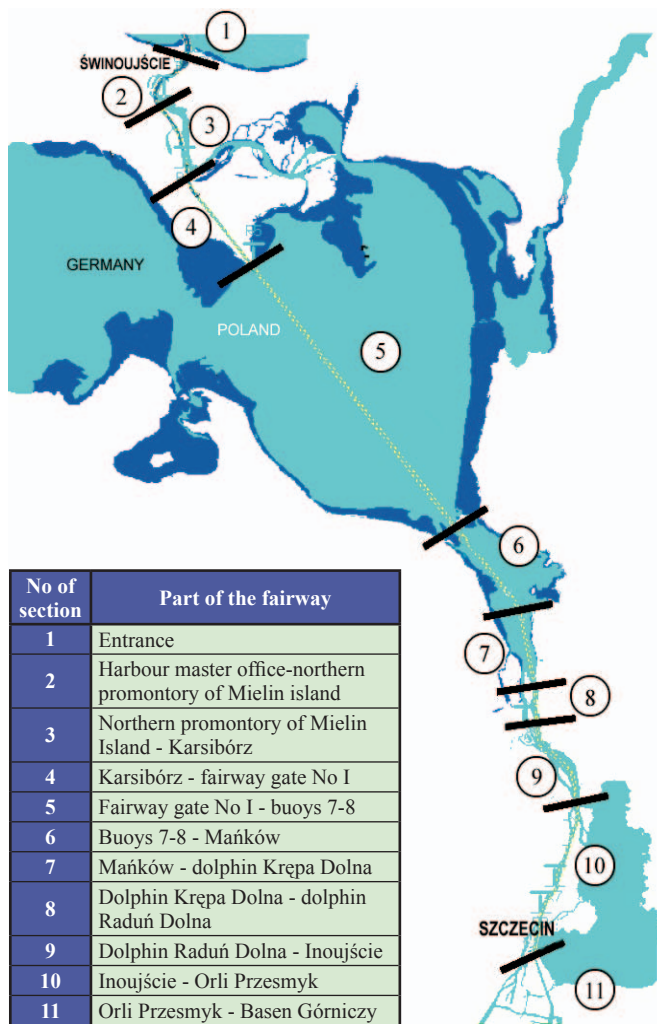

No of section	Part of the fairway
1	Entrance
2	Harbour master office-northern promontory of Mielin island
3	Northern promontory of Mielin Island - Karsibórz
4	Karsibórz - fairway gate No I
5	Fairway gate No I - buoys 7-8
6	Buoys 7-8 - Mańków
7	Mańków - dolphin Krępa Dolna
8	Dolphin Krępa Dolna - dolphin Raduń Dolna
9	Dolphin Raduń Dolna - Inoujście
10	Inoujście - Orli Przesmyk
11	Orli Przesmyk - Basen Górniczy

Fig. 1. Świnoujście-Szczecin fairway and its sections .

Each questionnaire consists of assessment of several manoeuvres. Thirty two pilots took part in the research. Nine the same manoeuvres were assessed by all the pilots.

When establishing the range of vessel dimensions two restrictions were considered. On the one hand the assessed manoeuvres should be those permitted by harbour regulations (slight violations can be accepted). Firstly this restriction is due to the fact that manoeuvres not permitted by the regulations could be considered by pilots as unsafe, secondly because only such manoeuvres can be considered as performed by pilots in the past. On the other hand the results of trial questionnaire showed that the assessments of manoeuvres of small vessels (about 80 m in length) never exceeded „2" in 10-degree scale regardless of the waterway section. This may lead to the conclusion that for such vessels traffic control is not necessary.

THE RESULTS

Assessing the safety level of a passing manoeuvre the pilot must take into consideration a number of factors. To find out how pilots' assessment is performed, one must answer several questions regarding the significance and influence of particular factors. What is the effect of vessels' dimensions ? Which dimensions can be considered as influential ? Could the same manoeuvre executed in different meteorological conditions be assessed at a different safety level ? Is the visibility restricted to 5 Nm an influential factor ? How does the night time affect pilot's opinion ? To answer questions like these the regression analysis, the most widely applied of all statistical techniques, can be used.

The regression model aims to determine how a set of variables (in this research : vessels dimensions, hydrological and meteorological conditions) is related to another variable in question (safety level). Like other models it represents a simplified description of reality, i.e. that neglecting elements non-essential for the researcher. Such simplification makes the problem easier to understand, but one should bear in mind that an excessive simplification needs unrealistic presumptions.

An equation or equations of the model are usually represented in a standardised form containing the looked-for (dependent) variable and influencing (independent) variables (predictors).

$$Y = b_0 + b_1X_1 + b_2X_2 + ... + b_nX_n \qquad (1)$$

where :

Y – dependent variable
X_1 , X_2 ... X_n – independent variables
b_0 , b_1 ... b_n – equation coefficients.

To select the best set of predictors is an important problem. Such variables should take into consideration the aim of the research – descriptive or prognostic one, and assure a sensible interpretation and description of the dependent variable with sufficient accuracy.

The approach chosen to solve the problem of the variable selection is sometimes called the experiment planning or backward elimination. Such an approach is convenient when the best-fitting regression equation is not needed, but only to find out the significance of independent variables in predicting the dependent variable (pilots' assessment) is needed. The vessel's dimensions and parameters describing hydrological and meteorological conditions were assumed the independent variables. Almost all variables are of qualitative nature. The only categorical (dummy) variable is a part of the day : day or night. To identify its significance it is denoted as follows :

0 – day
1 – night.

According to the taken presumptions the description is important only when it confirms statistical relations between the predictors and pilot's assessment. Such relation can be confirmed by using the *t-Student* test used to verify a hypothesis concerning regression equation coefficients. The assumed significance level was 0.05.

$\mathbf{H_0}$: $b_i = 0$ and the alternative hypothesis $\mathbf{H_1}$: $bi \neq 0$

The optimum decision allows to reject $\mathbf{H_0}$. This confirms the significance of the variable. The acceptance of $\mathbf{H_0}$ means that the dependent variable is not affected by this predictor or that the influence of this predictor cannot be precisely determined. The confirmed significance of the predictors allows to incorporate them into the equation. In the regression model

the correlation between independent and dependent variables is important, but it is also important to select such variables which are not mutually correlated.

Predictors which describe vessels should take into consideration dimensions of both vessels because one can not assume safety level of passing manoeuvre of vessels knowing length, breadth and draught of one vessel only. However it is possible to include into the equation the variables which are sums of corresponding dimensions, but first it must check if there is no correlation between the variables.

When verifying if a correlation between independent variables does not exist the correlation factors matrix shown in Tab.1 can be used. These factors are measures of correlation between pairs of independent variables. If two variables are strongly correlated it can affect estimation procedure of regression parameters.

The results presented in Tab.1 show strong correlation between two variables: *sum_of_lengths* and *sum_of_breadths*. This result makes it impossible to include into the equation the variables which are sums of corresponding dimensions (length and breadth). They can be replaced with a new predictor, i.e. sum of the products of the two dimensions, called the *sum_of_waterplanes*.

$$\text{sum\_of\_waterplanes} = L_1 \cdot B_1 + L_2 \cdot B_2 \qquad (2)$$

where :

B_1 , B_2 – breadths of considered vessels
L_1 , L_2 – lengths of considered vessels .

Tab. 1. Correlation of pairs of variables .

VARIABLE	Sum_of_ lengths	Sum_of_ breadths	Sum_of_ draughts	Night	Visibility	Wind force
Sum_of_ lengths	1.0000	0.9124	0.7222	- 0.0000	0.0000	0.0000
Sum of_ breadths	0.9124	1.0000	0.7394	0.0000	0.0000	- 0.0000
Sum of_ draughts	0.7222	0.7394	1.0000	- 0.0000	0.0000	- 0.0000
Night	- 0.0000	0.0000	- 0.0000	1.0000	0.0542	- 0.1259
Visibility	0.0000	0.0000	0.0000	0.0542	1.0000	- 0.3937
Wind force	0.0000	- 0.0000	- 0.0000	- 0.1259	- 0.3937	1.0000

Acceptance of the five variables: *sum_of_waterplanes, sum_of_draughts, night, visibility, and wind force* allows to create the following testing hypotheses :

$$\mathbf{H_0^1}: b_{sum\_of\_waterplanes} = 0$$
and alternative hypothesis
$$\mathbf{H_1^1}: b_{sum\_of\_waterplanes} \neq 0$$

$$\mathbf{H_0^2}: b_{sum\_of\_draughts} = 0$$
and alternative hypothesis
$$\mathbf{H_1^2}: b_{sum\_of\_draughts} \neq 0$$

$$\mathbf{H_0^3}: b_{night} = 0$$
and alternative hypothesis
$$\mathbf{H_1^3}: b_{night} \neq 0$$

$$\mathbf{H_0^4}: b_{visibility} = 0$$
and alternative hypothesis
$$\mathbf{H_1^4}: b_{visibility} \neq 0$$

$$\mathbf{H_0^5}: b_{wind\,force} = 0$$
and alternative hypothesis
$$\mathbf{H_1^5}: b_{wind\,force} \neq 0$$

In Tab. 2 are shown the results of the tests of significance of the predictors for the section no. 4 and 6 of the waterway. The results of the tests for the other sections are similar.

Tab. 2. Results of tests of significance of predictors for the section no. 4 and 6 .

Section no. 4			
PREDICTOR	**b**	$\mathbf{t_{(204)}}$	**p**
Sum_of_waterplanes	0.000223	2.20254	**0.028747**
Sum_of_draughts	0.346985	3.45112	**0.000678**
Night	0.096538	0.35815	0.720601
Visibility	- 0.113797	- 3.06849	**0.002444**
Wind force	0.008238	0.40967	0.682481
Section no. 6			
PREDICTOR	**b**	$\mathbf{t_{(204)}}$	**p**
Sum_of_waterplanes	0.000266	3.08243	**0.002337**
Sum_of_draughts	0.416491	4.85477	**0.000002**
Night	0.001524	0.00662	0.994721
Visibility	- 0.066313	- 2.09560	**0.037351**
Wind force	0.021087	1.22893	0.220513

The presented results confirm that the three predictors: *sum_of_waterplanes*, *sum_of_draughts* and *visibility* are significant. $\mathbf{H_0}$ hypotheses for the other variables cannot be rejected. This may lead to the conclusion that *wind force* (because of a short time of manoeuvre) and *the time of day* does not affect pilots' assessment.

An obvious way to assess the regression equation is to assess how well a set of independent variables correlates with the dependent variable. Measures of fitting are the variance and standard deviation of the rests, and the coefficient of determination. Measures of accuracy are standard deviations of the coefficients.

The coefficient of determination $\mathbf{r^2}$ is the percentage of total variance explained by the model. It is an indicator of the model fit [1] :

$$r^2 = \frac{SSE}{SST} \qquad (3)$$

where :

SSE – sum of squares of errors
SST – total sum of squares .

This coefficient can be also adjusted with the number of degrees of freedom; it has the following form :

$$r_{(adj)}^2 = 1 - \frac{n-1}{n-k-1}(1-r^2) \qquad (4)$$

where :

n – number of observations
k – number of predictors .

Another measure of model fitting is the root mean square error (or mean standard error) :

$$s = \sqrt{MSE} \qquad (5)$$

where :

MSE – the mean square error.

$$MSE = \frac{SSE}{n-(k+1)} = \frac{\sum_{j=1}^{n}(y_j - \hat{y}_j)}{n-(k+1)} \qquad (6)$$

where :

y_j – actual value of dependent variable
$\hat{y}_j$ – predicted value of dependent variable .

Tab. 3. *Coefficient of determination, adjusted coefficient of determination, F-statistic and mean standard error, for the equation of three variables : sum_of_waterplanes, sum_of_draughts and visibility .*

Number of section	r^2	$r^2_{(adj)}$	$F_{(3.206)}$	p	s
1	0.34344	0.33387	35.91831	< 0.00001	1.81659
2	0.25954	0.24876	24.06834	< 0.00001	1.64267
3	0.22717	0.21591	20.18418	< 0.00001	1.89743
4	0.23437	0.22322	21.02033	< 0.00001	1.90984
5	0.29764	0.28741	29.09912	< 0.00001	1.84703
6	0.34136	0.33177	35.58822	< 0.00001	1.63436
7	0.32367	0.31382	32.86169	< 0.00001	1.69795
8	0.31178	0.30176	31.10757	< 0.00001	1.63894
9	0.32447	0.31463	32.98172	< 0.00001	1.56115
10	0.31313	0.30312	31.30318	< 0.00001	1.60150
11	0.40054	0.39181	45.88091	< 0.00001	1.51395

Tab.3 shows values of the coefficient of determination, the adjusted coefficient of determination and the mean standard error for the equation of three variables : *sum_of_waterplanes, sum_of_draughts and visibility*. It also shows an F-statistic analysis of variance, which confirms the relation between the dependent variable and any of independent variables. The equation is based on 210 examples assessed by different pilots.

The obtained values of the coefficient of determination show that only a small percentage of total variance can be explained by the model. Nevertheless, obtaining the best-fitting prediction was not the purpose of this part of research; it was the confirmation if the predictors affect the dependent variable. Due to such factors like the inaccuracy of measurement (expert's assessment based on specific professional experience), existence of neglected parameters of the phenomenon in question (i.e. water current, ship's speed) or the lack of a proper expert's knowledge, the used model is not able to account for everything, thus errors are unavoidable.

The equation fits the data better when the set of three variables the significance of which was confirmed by tests, is included in the equation and mean values of all pilots' assessments are taken into account. Tab.4 shows values of the coefficient of determination, the adjusted coefficient of determination, the F-statistic analysis of variance and the mean standard error for the equation with the three variables. The equation is based on nine examples, each assessed by all 32 pilots. The mean values of assessments are taken into account.

Tab. 4. *Coefficient of determination, adjusted coefficient of determination, F-statistic, and mean standard error, for the equation with three variables : sum_of_waterplanes, sum_of_draughts and visibility. Mean values of all pilots' assessments are taken into account .*

Number of section	r^2	$r^2_{(adj)}$	$F_{(3,5)}$	p	s
1	0.92816	0.88506	21.53373	0.00274	0.52673
2	0.96134	0.93814	41.44007	0.00059	0.28332
3	0.94253	0.90804	27.33268	0.00158	0.43437
4	0.91715	0.86744	18.45003	0.00390	0.46360
5	0.88738	0.81981	13.13251	0.00831	0.61021
6	0.95045	0.92072	31.96948	0.00109	0.48449
7	0.92279	0.87646	19.91910	0.00328	0.54660
8	0.92991	0.88785	22.11112	0.00258	0.53383
9	0.93428	0.89485	23.69487	0.00220	0.48674
10	0.92943	0.88709	21.95142	0.00263	0.52384
11	0.92411	0.87858	20.29546	0.00314	0.57119

Tab.5 shows the constant and coefficients **b** attributed to the variables: *sum_of_waterplanes, sum_of_draughts* and *visibility* for all eleven sections of the Świnoujście-Szczecin fairway. Fig.2 shows the coefficients **b** attributed to the same three variables for all eleven sections of the Świnoujście-Szczecin fairway.

Tab. 5. *The coefficients **b** attributed to the variables: sum_of_waterplanes (b_1), sum_of_draughts (b_2) and visibility (b_3) for all eleven sections of the Świnoujście-Szczecin fairway (b_0 - constant). Mean values of all pilots' assessments are taken into account .*

| Number of section	b_0	b_1	b_2	b_3
1	2.253766	0.000615	0.115413	- 0.169931
2	2.117815	0.000429	0.056652	- 0.157979
3	0.564922	0.000479	0.229381	- 0.139367
4	0.369852	0.000415	0.196733	- 0.128929
5	- 1.287264	0.000308	0.342393	- 0.154076
6	- 0.067514	0.000548	0.322482	- 0.152738
7	- 1.034664	0.000375	0.381633	- 0.142633
8	- 0.213562	0.000371	0.414399	- 0.137965
9	0.243243	0.000429	0.274761	- 0.168543
10	0.489656	0.000457	0.295718	- 0.157638
11	- 0.206354	0.000388	0.452058	- 0.099156
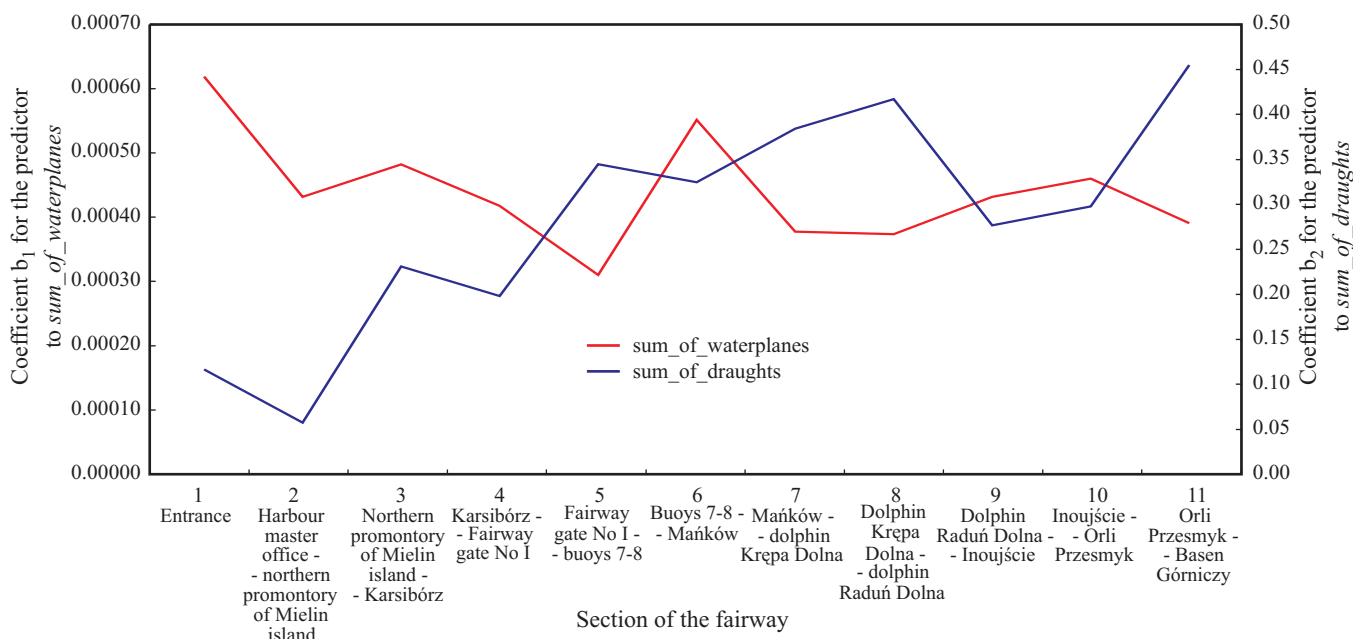
Fig. 2. *The coefficients **b** attributed to the variables : sum_of_waterplanes and sum_of_draughts .*

The values of coefficients for different sections are similar except for the sections no.2 and 5. In the section no.2 which includes the fairway of the port of Świnoujście with the depth of 14.3m, the value of the coefficient **b** attributed to the variable *sum_of_draughts* is distinctly lower, compared to those related to the other sections. In the section no.5 which leads through the Gulf of Szczecin, the value of the coefficient **b** attributed to the variable *sum_of_waterplanes* is distinctly lower than for the other sections, while the coefficient **b** attributed to the variable *sum_of_draughts* can be regarded as affecting the pilots' opinions.

Example :

with three predictors assumed, the equation
for the section no.7 is as follows :

$$(assessment) = -1.03466 + 0.00037 \cdot (sum\_of\_waterplanes) + 0.38163 \cdot (sum\_of\_draughts) - 0.14263 \cdot (visibility)$$
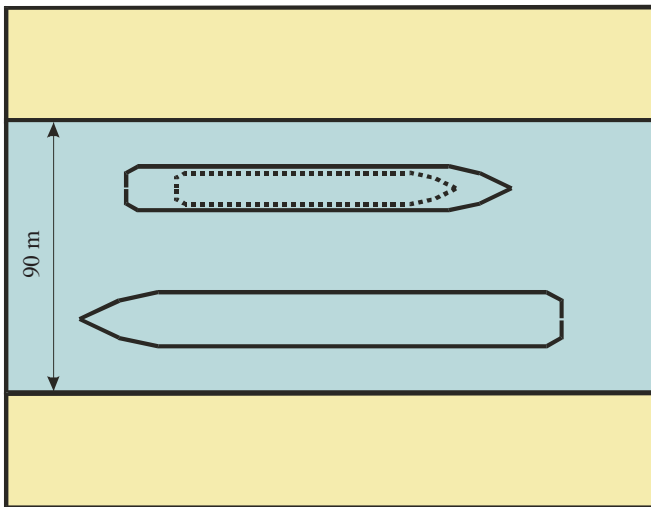

Fig. 3. *Passing manoeuvre .*

The manoeuvre of two ships passing each other and having the parameters : L_1=150 m, B_1=18 m, T_1=7 m; L_2=120 m, B_2=15 m and T_2=5 m, respectively (shown in Fig. 3 with solid line), in the visibility of 10 Nm, was assessed by the pilots at the value of 3.81 in 10 - degree scale. The same manoeuvre in the visibility reduced to 0.5 Nm was assessed at the value of 5.16. Also, can be compared two manoeuvres given with the same mark in two different visibility conditions, i.e. the good visibility (10 Nm) and that reduced to 0.5 Nm. The assessment value of 3.81 calculated for the above described manoeuvre can be assigned to the manoeuvre in the reduced visibility only when the dimensions of ships are adequately smaller. With the draught unchanged, the length and beam of one of the vessels should be equal to L_2= 88 m and B_2 = 10 m (shown in Fig.3 with the dotted line).

CONCLUSIONS

❍ Assessing a given situation, when manoeuvring in restricted areas, the pilot must take into consideration a great number of factors. The creation of a decision support systems based on experts' knowledge and experience, seems to be a useful and helpful solution. Such systems can solve complex problems of a very specific nature with results comparable to those provided by an expert, for example a pilot.

❍ When a traffic regulation is established in a specific area, decisions related to planning the passage of vessels are not made by the pilot but by a person who has no such professional shiphandling experience. His or her decisions are based on harbour regulations or internal procedures which must be a simplification of pilots' experience.

❍ The knowledge acquisition process is laborious and long--lasting, so the creation of decision support system is reasonable only when it has to be used by a great number of users and for a long time.

❍ There are opinions that the main task of an expert is to tackle identification of a hazard or risk. Anybody with great professional experience can easily point out situations connected with hazard or risk. The results presented in the paper show that an expert opinion can be also used for risk classification.

❍ Finally, all activities undertaken by all the persons engaged in safety matters in restricted waters can be treated as the activities undertaken within one system which needs interdependent decision - making and operations. The system in which decisions made by persons in charge of the vessel and a shore-based VTS centre interact each other, really exists. The interaction must be taken into consideration by all parties because decisions made by one party affect the other parties in an intended or unintended manner.

NOMENCLATURE

b – equation coefficient
B – vessel's breadth
F – F-statistic
L – vessel's length
p – significance level
r^2 – coefficient of determination
$r^2_{(adj)}$ – adjusted coefficient of determination
s – mean standard error
t – t-statistic
T – vessel's draught
VTS – Vessels Traffic Service
Y – dependent variable
X – independent variable.

BIBLIOGRAPHY

1. Aczel A. D.: *Statistics in management* (in Polish), Scientific Publishers (Wydawnictwo Naukowe) PWN. Warszawa, 2000
2. Ayyub B. M.: *Elicitation of Expert Opinion for Uncertainty and Risk*, CRC Press LLC. Boca Raton, 2001
3. Boisson P.: *Safety at sea – Policies, Regulations & International Law*, Bureau Veritas. Paris, 1999
4. Cieślak M.: *Predicting in economy. Methods and applications* (in Polish), Scientific Publishers (Wydawnictwo Naukowe) PWN. Warszawa, 2001
5. Filipowicz W.: *Problems of ship traffic management – PLA* (Population Learning Algorithms) *approach* (in Polish), Reports of Navigation Department, Gdynia Maritime University (Prace Wydziału Nawigacyjnego Akademii Morskiej) No. 13. Publishing House of Gdynia Maritime University. Gdynia, 2002
6. Klein M. R., Methlie L. B.: *Knowledge-based Decision Support Systems with Application in Business*. John Wiley & Sons Ltd. Chichester, 1995
7. Korbicz J., Kościelny J. M., Kowalczuk Z., Cholewa J.: *Process diagnostics. Models. Artificial intelligence methods. Applications* (in Polish). Scientific Technical Publishers (Wydawnictwo Naukowo-Techniczne). Warszawa, 2002
8. Luszniewicz A., Słaby T.: *Statistics. Theory and applications* (in Polish). 2nd ed., C.H. Beck Publishers. Warszawa, 2003
9. Mulawka J.: *Expert systems* (in Polish). Scientific Technical Publishers (Wydawnictwo Naukowo-Techniczne). Warszawa, 1996

10. Pietrzykowski Z., Narękiewicz M.: *Implementation of marine regulations in decision support system for vessel traffic services*. Maritime Engineering & Ports. WIT Press. Southampton, 2002

11. Wawruch R., Śniegocki H.: *System of ship traffic surveillance as a body for control and organization of ship traffic at sea* (in Polish). Reports of Navigation Department, Gdynia Maritime Academy (Prace Wydziału Nawigacyjnego Wyższej Szkoły Morskiej w Gdyni) No. 4. Publishing House of Gdynia Maritime Academy. Gdynia, 1997

12. Zieliński J. S.: *Intelligent systems in management. Theory and practice* (in Polish). Scientific Publishers (Wydawnictwo Naukowe) PWN. Warszawa, 2000

13. Ziembiński Z.: *Practical logics* (in Polish). Scientific Publishers (Wydawnictwo Naukowe) PWN. Warszawa, 1994

14. Polish Ministry of Infrastructure. Official Journal No 4, item 41. Warszawa, 2003 .

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*C*onference

SHA 2005

On 16-19 May 2005 at Puck, a Polish town
on the coast of the Gulf of Gdańsk,
was held 5th in Poland

European Acoustics Association (EAA) Symposium on Hydroacoustics.

It was organized by Polish Naval University, Gdynia. As usually, the main topics of the scientific meeting were the following :

- ★ Acoustics in fisheries
- ★ Acoustics in marine environment
- ★ Non-linear acoustics
- ★ Sound propagation in the sea – modelling
- ★ Radiated and ambient noise
- ★ Sonar systems
- ★ Signal and data processing
- ★ Transducers and instrumentation.

34 submitted papers were devoted to research results and theoretical considerations presented by scientific workers from 11 Polish scientific research centres including Gdańsk University of Technology (10 papers), and 8 foreign centres including 4 Russian ones (4 papers) and those of Austria, Canada, Turkey and United Kingdom (1 paper each). All the papers have been very carefully published (in Polish) as the Symposium's proceedings by Polish Acoustical Society, Gdańsk Division, in the Annual Journal „Hydroacoustics", vol.8, Gdynia 2005.

*C*onference

A sailing conference

The next successive
Domestic Scientific Conference on :

Scientific and technical problems of professional sailing

was organized by the Faculty of Motor Cars and Heavy Machinery, Faculty of Mechanics, Energy and Aeronautics of Warsaw University of Technology together with the Faculty of Mechanical Engineering of Gdynia Maritime University.

It was held on 2-9 April 2005 on board the sailing yacht *Pogoria* during its voyage on the route : Naples – – Castellamare – Civittaveccia – Livorno – Geneva, and its programme contained the presentation of 25 papers prepared both by scientific workers and students. The papers were divided into four topical groups :

❖ *Calculation methods, measurements and materials*
  10 papers including 3 prepared by students :

  ➢ *Measurement of hull form by using tachimetric methods* – by A. Klawikowska and B. Puchowski under supervision of J. Kozak, D.Sc. (Gdańsk University of Technology)
  ➢ *Numerical analysis of a keel-rudder system by using Fluent software* – by A. Sentkowska and J. Broniszewski (Warsaw University of Technology)
  ➢ *Analysis of influence of spreader inclination angle on magnitude of compressive force acting on the mast and stress distribution within the mast* – by M. Zagożdżon (Warsaw University of Technology) .

❖ *Construction, building and general arrangement*
  6 papers including 4 prepared by students :

  ➢ *A fast water craft driven by human muscles* – by W. Leśniewski and K. Niklas (Gdańsk University of Technology)
  ➢ *Design study of a small yacht* – by Z. Madej (Silesian University of Technology)
  ➢ *Tests of a prototype sailing yacht* – by D. Markuszewski and M. Wędołowski (Warsaw University of Technology)
  ➢ *Flybridge as an element of Sunreef 60' turistic catamaran* – by E. Perzyk (Warsaw University of Technology) .

  ❖ *Safety and operation* – 6 papers

  ❖ *Mechanical drives* – 3 papers

The greatest number of papers (8) was prepared by representatives of Warsaw University of Technology, 4 papers by authors from Mining- Metalurgical Academy, and 2 papers by authors from Gdynia Maritime University. Authors from Gdańsk University of Technology, Koszalin Technical University, Silesian University of Technology and Technical-Humanistic Academy of Bielsko-Biała presented one paper each.