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# Editorial

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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 :

## **Engineering, Computing & Technology, Mechanical Engineering,**

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.

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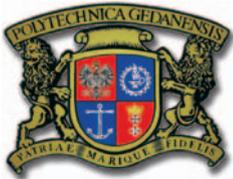
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# A new curriculum on Numerical Methods in Mechanics and Design. Is it shipbuilding-like enough?



## ABSTRACT

*The paper describes a new curriculum for teaching computing methods in mechanics and design developed at Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology, which has been introduced beginning from summer semester 2005. The new specialization covers the last 5 semesters (6 - 10) of the unified M.Sc. course in Ocean Technology. All courses of the new specialization are given in English. The objective of the new curriculum is to educate engineers skilful in applying modern modelling technologies for practical solving problems of structure and fluid mechanics, heat transfer and automatic control in the area of marine industry. The curriculum has been endorsed by General Electric (GE) as unique, novel and advanced one – moreover the company took patronage over the specialization. Similar encouragement has been obtained from PRS, LR, ABB and UGS when the idea of the course was presented on a special seminar.*

The Faculty of Ocean Engineering and Ship Technology of Gdańsk University of Technology educates specialists in Naval Architecture and Marine Engineering. The 10-semester integrated M.Sc. course is divided into 2 parts: the first part (of 5 semesters) gives the student basic, fundamental knowledge in mechanical engineering, naval architecture and marine engineering, while the second part (of 5 semesters) is focused on the specialization and development of M.Sc. thesis.

For a long time the Faculty authority has observed that there is a growing demand for specialists well prepared and flexible in applying modern technologies for modelling and solving problems of structural mechanics, fluid dynamics, heat exchange and control in the fields of marine engineering and naval architecture. There is also growing practice for design testing at early design stages, product improvement analyses, estimation of product reliability by determining probable failure modes. All these activities demand to use computational methods because of costs and time of experiments, if such experiments are possible at all. Specialists skilful in such areas are needed by design computational centres, consulting companies, classification societies and maritime industry companies.

The maritime industry as well as mechanical engineering field requires „hard skills” in modelling and computing, since more and more prototyping tasks is being moved into computer virtual field. For graduates the possessing of such skills means employment security and independence. They have to be flexible, ready to look for jobs and to develop themselves into new areas. If modelling principles, theories, practical skills, capabilities to judge the obtained numerical results, and knowledge of experimental methods are mastered by graduates then it is easy for them to adapt to new challenges in new industries.

Advanced maritime industries like in South Korea do utilise knowledge and the highest skills (in that country 25% of employees of ship design offices hold Ph.D. degree, and 55% – M.Sc. degree). What counts today is the capability to model phenomena for design, operational and managerial purposes. This capability is leveraged by using advanced CAD/CAE techniques in the design, manufacturing and product maintenance processes. The modern researcher and engineer is capable of rapid adoption of new technologies, which means continuous learning, system approach and the ability to implement new tools for his tasks. Young engineers have to possess capabilities to manage projects of various scale, including international projects (and the latter requires that they are fluent in English in managerial and technical tasks).

The Faculty’s M.Sc. standard courses on Ocean Engineering (OE) – similarly to standard courses at mechanical engineering departments – give only partial training in the mentioned expertise areas, mainly because such studies are mainly aimed at educating broadly prepared designers. The present syllabus does cover many important subjects related to modelling and computing technologies, but the time devoted to the subjects is rather limited and most of work is done by students themselves during extra curriculum courses and thesis preparation. The semesters 1 ÷ 5 of the M.Sc. course provide broad basis, general engineering education, present basic problems in Naval Architecture (NA) and Marine Engineering (ME). The semesters 6 ÷ 9 serve for broadening the knowledge either in NA or ME, and the semester 10 is for diploma specialization (research and thesis preparation). There do exist „computational courses” like those on structural mechanics, CFD, modelling of strength of structures. However, the imperfections of the present model in the „computational” aspect are the following:

- ⇒ lack of large course blocks devoted to the problems of modelling
- ⇒ small number of projects which usually do not require advanced modelling
- ⇒ large number of specialization courses which limit the scope of knowledge to be presented to students, and finally
- ⇒ the specialization in computational methods usually takes place during research on thesis and it is based on individual studies on problems and supporting software (necessarily in somehow limited scope and not structured to serve for future development).

The Faculty's authority has observed that there is a need for a structured programme aimed at the development of mathematical modelling techniques, for furnishing students with solid fundamentals in computational methods used for modelling and problem solving in the mentioned expertise areas, for teaching practical problem solving techniques with the use of modern software and for the development of capabilities of organising and managing the project work.

All the observations led us to the development of the new specialization named :  
**Numerical Methods in Mechanics and Design.**

- The fundamental thinking during development of the specialization curriculum was as follows.

The objective was to provide good, broad, professional preparation of students. They would master the skill of fast and independent learning. The course in question was aimed at providing deep – both theoretical and practical – knowledge about modelling techniques used in structural mechanics, fluid flow and heat exchange, and in control. We aimed at providing an experience in practical solving computational problems with the use of industry-applicable software systems. At the same time we would like to instil a critical attitude toward employed models through pointing the need of model verification and correlation with experiments. We aimed at developing project managerial skills by requiring to plan, perform and manage many various design projects.

- The assumptions for development of the specialization courses are as follows :
  - ⇒ we would focus on theories and practice important for the mathematical modelling problems and related computational methods applicable in ocean engineering (naval architecture, power plants, deck equipment)
  - ⇒ we would expand the knowledge and to give the students the opportunity for practical application of the knowledge – presenting them a large set of design projects

from the field of ocean engineering and requiring them to study, analyse and model the designs and to draw engineering conclusions

- ⇒ we would support and develop their professional education by set of courses on ship structures, turbines, hydrodynamics, machine design, advanced material sciences (including basis of nanotechnology)
- ⇒ we would support the core courses by the topics important for modelling techniques and team-work: topology, project management and advanced CAD/CAE systems
- ⇒ the specialization courses would be given in English, because the graduates will work in international environment (at present, we have a 120 - hour intensive English language course during 2<sup>nd</sup> and 3<sup>rd</sup> semester).

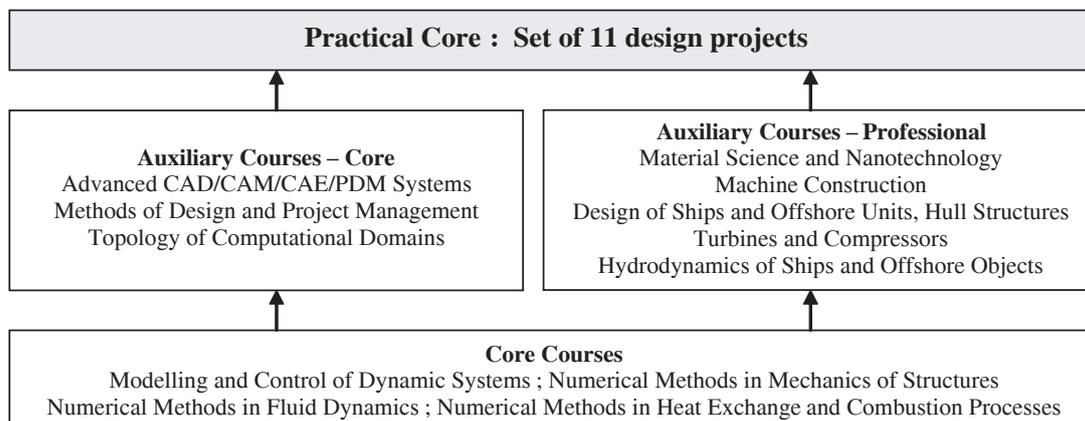
The specialization programme is designed for a small group of students (15 ÷ 18 persons). It allows for flexibility in lecturing, namely for easy illustration of lectures by laboratory work and demonstrations. The division of courses is shown in Tab.1. and the detailed study plan in Tab.2, while Fig.1 shows the interdependence between basic courses, advanced courses and design projects during the studies.

*Tab. 1. Layout of courses during semesters for specialization in Numerical Methods in Mechanics and Design .*

10	Research and thesis	
9		<b>Designs</b>
8	Core courses	<b>Designs</b>
7	Core and auxiliary courses	
6	Core and auxiliary courses	
1 – 5	<i>Basic standard OE courses</i>	

Generally, the specialization requires total of about 1530 hours of classes in the semesters 6 ÷ 9. The core and auxiliary courses are assigned to the semesters 6, 7, and 8, while the design projects to the semesters 8 and 9. The thesis are planned for the semester 10 (students may start the research earlier). We also provide practical professional training : after 6<sup>th</sup> semester (6 weeks) and after 8<sup>th</sup> semester (4 weeks).

The design project, a very important phase in the curriculum, takes 45 hours in a semester. About 15 hours are planned for studying the problem and specific methods for its modelling. The remaining hours are planned for the modelling, analysis and conclusions.



*Fig. 1. Progress and classification of courses for specialization in Numerical Methods in Mechanics and Design .*

Tab. 2 contains the plan of studies which shows the specific courses and their arrangement for the specialization in *Numerical Methods in Mechanics and Design*.

Tab. 2. Plan of studies for the specialization in *Numerical Methods in Mechanics and Design*.

Sem.	Course name	Lecture	Lab.	Proj.	Seminar	Assess.	Type
6	Modelling and Control of Dynamic Systems	4	2			Exam	Core
6	Material Science and Nanotechnology	4	2			Credit	AuO
6	Advanced CAD/CAM/CAE/PDM Systems	1	5			Credit	AuC
6	Methods of Design and Project Management	4				Credit	AuC
6	Design of Ships and Offshore Units Hull Structures	4				Credit	AuO
6	Machine Construction	4				Credit	AuO
7	Numerical Methods in Mechanics of Structures	5	3			Exam	Core
7	Numerical Methods in Fluid Dynamics (Incompressible flow) – 1	2	2			Exam	Core
7	Topology of Computational Domains	3	3			Credit	AuC
7	Turbines and Compressors	4				Credit	AuO
7	Hydrodynamics of Ships and Offshore Objects	3	1			Credit	AuO
7	Control Design for Dynamic System			3		Credit	Cdes
8	Numerical Methods in Fluid Dynamics (Compressible flow) – 2	4	2			Exam	Core
8	Numerical Methods in Heat Exchange and Combustion Processes	4	2			Exam	Core
8	Free-Surface Flow around Ship's Hull			3		Credit	Cdes
8	Air Flow around Ship's Superstructure and Hull			3		Credit	Cdes
8	Stresses and Deformations of Machine Elements			3		Credit	Cdes
8	Vibrations of Machine Elements			3		Credit	Cdes
9	Strength and Vibrations of Ship Structure			3		Credit	Cdes
9	Project on Heat Exchangers			3		Credit	Cdes
9	Distribution of Temperature and Welding Stresses in Welded Joint			3		Credit	Cdes
9	Fuel Spraying and Combustion in Diesel Engine			3		Credit	Cdes
9	Flow Through a Turbine Stage			3		Credit	Cdes
9	Flow Within the Lubricating Film of Slide Bearing			3		Credit	Cdes
9	Physical training				2		
10	Diploma seminar				1	Credit	
10	Physical training				2		
<b>Note</b> : Classes are given in hours per week (15 weeks per semester). <b>Abbreviations</b> : Lab. – laboratory, Proj. – project, Assess. – Assessment, AuO. – Auxiliary Ocean Technology, AuC. – Auxiliary Core, Cdes. – Core Design		<b>Lecture</b>	<b>Lab.</b>	<b>Proj.</b>	<b>Seminar</b>	<b>Total hours</b>	
		46	22	33	5	1590	

The courses were prepared by the staff of the Faculty and the Institute of Fluid Flow Machinery of Polish Academy of Sciences. One may see that we have arranged the core and the auxiliary courses within the first 3 semesters, with the bulk courses concentrated on the first two of them. The first core courses are related

to the automatic control (6<sup>th</sup> semester), structural mechanics and incompressible flow (7<sup>th</sup> semester), and they are followed by the remaining core courses on heat transfer and compressible flow (8<sup>th</sup> semester). It allows us to gradually introduce the design projects, starting from a single project on control system design (7<sup>th</sup> seme-

ster), followed by 4 projects divided into structural mechanics and CFD problems for incompressible media (8<sup>th</sup> semester), and concluded by 5 projects dealing with compressible flow, heat transfer, structural mechanics and lubricating flow (9<sup>th</sup> semester). Such layout of courses allows for gradual introduction of complex subjects, provides necessary tools at proper time, maintains student interest (since the core courses contain use of hardware laboratories as well as computer exercises), and allows the students for more self-study and more independence on design projects at the end of studies. It also gives some flexibility to less capable souls to made-up some credits they missed on earlier semesters. The students do their research and elaborate their thesis during the last semester. The thesis writing should be an experience on a high and interesting level for the students as they would probably have already handled and solved – with some guidance – eleven diverse design projects.

We want to make clear to the students that the engineer – especially the computational expert working on phenomena modelling – works on models of reality. It demands of him a critical approach for the modelling results, consciousness that verification of the results is necessary, and that it is demanded of him not to hesitate to make experiments, accompanied by the knowledge how to conduct and evaluate the required experiments. For this we have provided the use of hardware laboratories – at the Faculty, at other faculties of the University and the Institute of Fluid Flow Machinery. The laboratories have to serve as lecture demonstrations, a place for selected experiments performed by students and a tool for professional training. We also provided a specialized (CAD/CAE orientated) computer laboratory fitted with modern equipment, connected to Faculty Intranet, equipped with professional software systems – to be used by future graduates in industry and continuously accessible for students.

We have also access to the following hardware laboratories :

**at our Faculty**

- ★ a ship hydrodynamic laboratory (towing tank, cavitation tunnel, circulating water channel)
- ★ a mechanical engineering laboratory (slide bearing test stand, rotor dynamic test stand, and hydraulic equipment test stand)
- ★ a control system laboratory (various control devices at educational computer-controlled settings)
- ★ a structural mechanics laboratory (deformations of ship structures)
- ★ a material science laboratory,

**at other scientific institutions**

- ☆ nanotechnology laboratory at the Faculty of Chemistry, Gdańsk University of Technology (GUT)
- ☆ aerodynamic laboratory – at the Institute of Fluid Flow Machinery, Polish Academy of Sciences
- ☆ combustion and heat transfer laboratory – at the Institute of Fluid Flow Machinery, Polish Academy of Sciences.

The access to the facilities gives the students a chance to fully develop their capabilities without leaning just on the computational modelling techniques, by requiring them to do some experimental work, to understand the limitation of the numerical models and to pay attention both to the real physical processes and theories which describe them. The rich laboratory environment gives also a chance to do validation and verification studies during development of student thesis.

The example of such approach is shown in Fig.2 which displays the air test turbine and its numerical model prepared for computations by using FLUENT software.

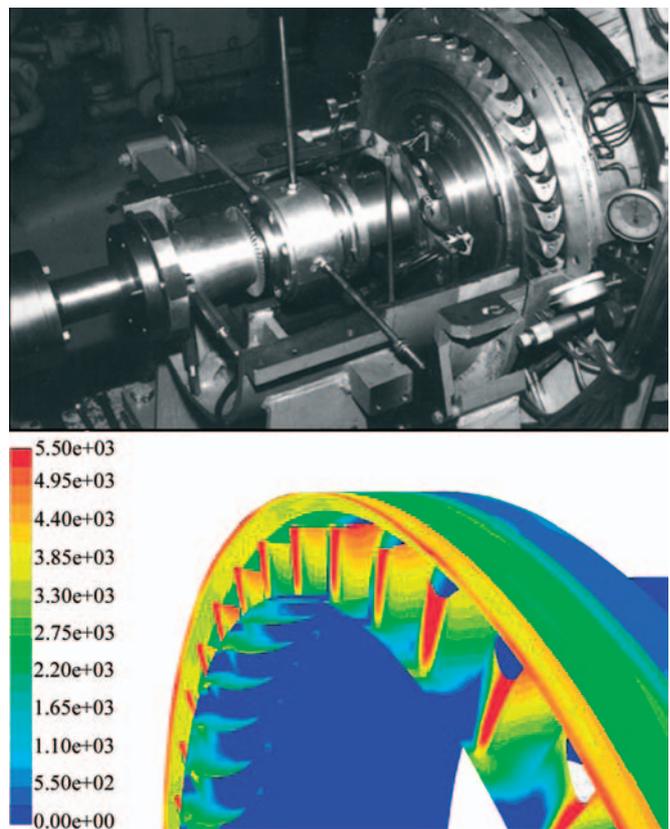


Fig. 2. View of the model turbine rotor – laboratory and computational model (courtesy of mr. Robert Stepień, M.Sc.).

Tab.3 shows the computer software to be used in the laboratory. The software has so far consisted of the following basic packages.

Tab. 3. Software packages used in the computer laboratory .

Application Area	Software
CAD/CAM/CAE/PDM	UNIGRAPHICS/SOLID EDGE
Dynamic system modelling	MATLAB/SIMULINK, MATHEMATICA
Structural mechanics	ANSYS, NASTRAN
CFD and heat transfer	FLUENT, ANSYS, PHOENICS
General office	MS OFFICE, Open Office

The first graduates of the specialization will leave the university in the year 2007. We can see that there is a potential for foreign students to join the studies in that unique specialization. The specialization is open for the Polish students from other faculties of GUT who would like to study mathematical modelling of structures, flow or control. The specialization may be also easily converted into M.Sc. studies (second level). Some specially crafted post-graduate courses in selected fields of mathematical modelling may be also developed for the industry needs (for example, „Computational methods in structural mechanics”, „Computational methods in fluid mechanics and heat transfer” or „Computational methods in fluid mechanics”).

The industry (shipyards, design offices, international product manufacturers) seems to be interested in the new course. In June 2005 we held a seminar with the industry to present our approach and proposal. The participants expressed ap-

preciation of the programme, gave their comments and said „we are waiting for your graduates”. There were also formal endorsements of the programme by companies like General Electric, ABB or Unigraphics Graphics Systems (UGS). They expressed their readiness to invite students for apprenticeships in Poland and abroad, as well as their wish to co-operate with the Faculty (special lectures for students) and to certificate the CAD course as „Advanced” (UGS).

There is also noticeable interest of foreign students to participate in the programme – we have already enrolled foreign students within ERASMUS exchange programme.

It is also worth noticing that the programme is challenging and interesting for the most promising students at the Faculty: we have asked the students of 4<sup>th</sup> semester to select their specialization, and about half of the group of excellent students (10 persons) have signed up to participate in the programme.

As for the initial question : *is it a shipbuilding-like specialization?* We think that it is the case :

- the core problems and applications come directly from the maritime industries

- the studies provide substantial basis that allow for development and work in the fields of ocean engineering
- the studies give good theoretical background and request individual studies and self-development from the students in order to be well prepared for the future jobs from the view point of independence, self-direction, and to be able to work as subcontractors
- it is a Hi-Tech specialization which supports development of the marine industry (since there are needs for new constructions, re-working and exploring new opportunities for design optimisation; therefore the graduates knowing the newest design aiding technologies are constantly sought - after).

### *About the author*

The author of this paper is **Wojciech. A. Misiąg**, D.Sc., who held, in the years 2002-2005, the post of Associate Dean for Education of the Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology.

FOREIGN

*conference*

## ISCORMA – 3

On 19-23 September 2005  
Cleveland, Ohio, USA, hosted :

### *The third International Symposium on Stability Control of Rotating Machinery*

ISCORMA Conferences were initiated at South Lake Tahoe, California in the year 2001, and continued by Polish scientists of Gdańsk University of Technology who organized 2<sup>nd</sup> Conference of the kind in Gdańsk in 2003.

Program of ISCORMA-3 was divided into 27 sessions during which 67 papers were presented. Their authors represented universities, research centers and industries of 10 European countries, Australia, Brazil, China, Egypt, India, Japan, Korea, Mexico, Taiwan and USA.

The number of papers of US authors (21 papers) of course prevailed in the scope of the Conference program; the next in number were those of Polish authors (7) and Japanese ones (5).

Polish authors presented the following papers:

- ✦ *Application of statistical methods for the evaluation of the condition of marine gas turbine engines and predicting the time of their faultless operation* – by A. Adamkiewicz (Polish Naval University)
- ✦ *Effect of bearing clearance on the dynamic characteristics of cylindrical journal bearing* – by S. Strzelecki and T. Zieliński (Łódź University of Technology)
- ✦ *Dynamic characteristics of cylindrical journal bearings with variable axial profile* – by S. Strzelecki (Łódź University of Technology) and S. M. Ghoneam (Menoufia University, Egypt)

- ✦ *Non-linear interactions in large power machine with cracked rotor* – by J. Kiciński and S. Banaszek (The Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Gdańsk)
- ✦ *Dynamic characteristics of tilting 5-PAD journal bearing* by S. Strzelecki (Łódź University of Technology)
- ✦ *Effect of design parameters on the dynamic characteristics of tilting - PAD journal bearings* – by S. Strzelecki and H. Kapusta (Łódź University of Technology)
- ✦ *Robust controllers for electrohydraulic actuators* by Z. Gosiewski (Białystok Technical University) and M. Henzel (Military University of Technology, Warsaw).

Besides, the group of Polish scientific workers, namely:

- W. Batko (AGH University of Science and Technology, Cracow)
- Z. Domachowski (Gdańsk University of Technology)
- Z. Gosiewski (Białystok Technical University)
- J. Kiciński (The Szewalski Institute of Fluid-Flow Machinery, Polish Academy of Sciences, Gdańsk)
- K. Kosowski (Gdańsk University of Technology)
- Z. Kozanecki (Łódź University of Technology)

took part in work of the International Scientific Committee consisted of 40 persons, and Z. Gosiewski acted as a member of 6-person Organizing Committee.

# Numerical evaluation of the wave pattern for fast ships with taking into account the dynamic trim and sinkage

**Marek Kraskowski**

Centrum Techniki Okrętowej S. A.  
(Ship Research and Design Centre)

## ABSTRACT



*This paper presents results of the numerical evaluation of the fast container ship's wave pattern, based on the RANSE (Reynolds-Averaged Navier Stokes Equations) method with dynamic trim and sinkage taken into account. Evaluating the ship's running attitude is based on coupling the flow solver with solving the motion equations for the ship hull. The results are presented for four speed values and contain: ship's running attitude (defined by changes of ship draught and trim angle), wave contours and wave profiles in chosen planes. The computed ship's running attitude and wave profiles are compared with the experimental results.*

Keywords : RANSE, free surface, fast vessels, dynamic trim and sinkage

## INTRODUCTION

Numerical tools enabling evaluation of the wave pattern are especially useful during initial optimization of the hull shape with respect to the wave-making resistance. The most important advantage of CFD (Computational Fluid Dynamics) methods is their low cost compared to the towing tank experiments. However to this time CFD calculations have been carried out mostly for fixed hull conditions, i.e. when dynamic trim and sinkage were neglected. Such approach is quite reasonable for low speeds when changes of trim and draught are so small that they have no noticeable influence on wave pattern, but it should not be used in the case of fast ships when the dynamic lift becomes significant.

Different approaches can be used for evaluating the running attitude of the ship, e.g. one can calculate it in an iterative manner by performing successive computations for fixed hull conditions and changing the position of the hull in each iteration basing on the computed forces and hydrostatic characteristics.

The presented method is based on coupling the RANSE solver for unsteady problem with solving the motion equations for the hull. Because exact history of hull motion is here of no importance, an artificial damping of the motion was used to improve stability of the procedure. The computations were carried out with the use of COMET flow solver extended with the user-programmed procedure for solving the motion equations.

## PRINCIPLES OF THE FLOW SOLVING METHOD

The idea of RANSE approach is to decompose the variables in Navier-Stokes equations into the mean (time-averaged) and fluctuating component. The velocity components  $u_i$  are thus decomposed as follows :

$$u_i = \bar{u}_i + u_i'$$

where  $\bar{u}_i$  is the mean velocity component and  $u_i'$  is the fluctuating component.

Likewise, pressure and other scalars are decomposed as follows :

$$\Phi = \bar{\Phi} + \Phi'$$

By substituting these expressions into the continuity and momentum conservation equations the following equations (for incompressible flow) are yielded :

continuity equation :

$$\frac{\partial}{\partial x_i} (\rho \bar{u}_i) = 0$$

momentum equation :

$$\begin{aligned} & \frac{\partial}{\partial t} (\rho \bar{u}_i) + \frac{\partial}{\partial x_j} (\rho \bar{u}_i \bar{u}_j) = \\ & = - \frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ \mu \left( \frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i} \right) \right] + \frac{\partial}{\partial x_j} (-\rho \overline{u_i u_j}) \end{aligned}$$

Terms  $(-\rho \overline{u_i u_j})$  are called Reynolds stresses which are additional unknown variables, hence additional equations are required to close the system of equations. The equations are called the turbulence model. In the presented case, the  $(k - \epsilon)$  turbulence model was used, in which two equations are solved, namely the transport equations of two turbulence parameters : its kinetic energy  $k$  and rate of dissipation  $\epsilon$  [3].

The RANSE approach can be shortly characterized as follows :

- the continuity and momentum conservation equations are solved for the averaged flow
- the turbulent flow is not calculated exactly. Instead, the turbulence is taken into account by solving the transport equations

for some statistic parameters of turbulence (in the presented case: turbulence kinetic energy and its rate of dissipation).

The numerical method used in this case for solving the partial differential equations is the Finite Volume Method. The idea of this method is to divide the considered flow domain into a finite number of control volumes (mesh generation) and to formulate equations in the integral form for each of the control volumes. The conservation equation for the general scalar quantity  $\Phi$  in the integral form is expressed as follows :

$$\int_S \rho \Phi V n dS = \int_S \Gamma \text{grad } \Phi n dS + \int_{\Omega} q_{\Phi} d\Omega$$

where :

- S – surface area which bounds the control volume  $\Omega$
- $\Phi$  – scalar field function
- V – velocity vector
- n – vector normal to control volume surface
- $\Gamma$  – diffusivity
- $q_{\Phi}$  – source of the quantity  $\Phi$

For each of the control volumes such equation is transformed into the algebraic equation by means of the discretization process, thus one obtains the system of algebraic equations which are to be solved in the iterative manner.

Because the flow around moving body is unsteady, the equation must be also discretized respective to time with a finite time step value.

The reason for using the Reynolds averaging instead of solving the exact Navier-Stokes equations is that the numerical method for exact equations would require:

- the size of control volumes comparable with the size of the smallest vortices in turbulent flow
- the time step value appropriate to resolve the unsteady phenomena of the turbulence.

For high Reynolds number (turbulent flow), to solve such problem is not possible because the necessary computational effort exceeds the possibilities of today's computers.

In the RANSE approach the size of control volumes and the time step should be appropriate to resolve the mean flow only. This greatly reduces the computational effort and still gives valuable results.

### METHOD FOR EVALUATING THE FREE SURFACE

The COMET solver used for the flow computations offers two methods for evaluating the free surface :

- ⇒ *interface tracking method* : the mesh of control volumes is deformed iteratively so as to satisfy the boundary conditions for free surface
- ⇒ *volume – of – fluid method (VOF)* : an additional equation is solved for the scalar quantity determining the volume fraction of water in each point. In this method the computational domain contains both air and water.

The idea of both methods is presented in the sketches below.

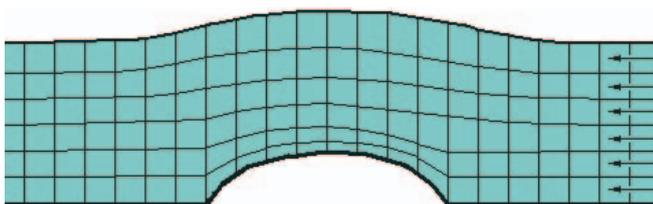


Fig. 1. Interface tracking method : the mesh is deformed to satisfy the boundary conditions for free surface .

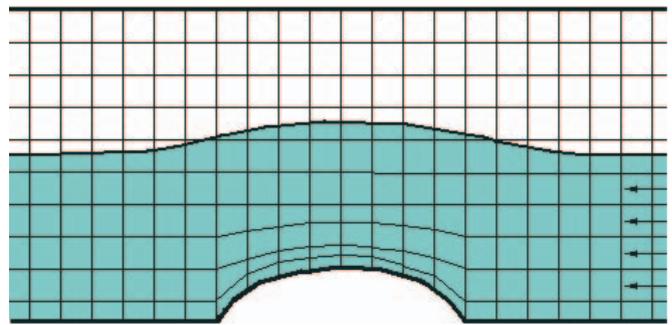


Fig. 2. Volume – of – fluid method (VOF) : the mesh is fixed, an additional equation for the fluid transport is solved .

The VOF method was chosen for the computations due to the following advantages of the method :

- ❖ There are no problems with complex geometries of the hull and such effects as wave breaking and air trapping which can occur in the flow around ship hull. In such case use of the interface tracking method would cause unacceptable distortion of the mesh cells
- ❖ The VOF method is more flexible when the dynamic mesh is applied, which is the case in the presented computations.

The VOF method is based on the following assumptions :

**The fluids filling the domain are treated as one fluid whose properties depend on :**

- ⊞ physical properties of particular fluids
- ⊞ local value of the so-called volume fraction C of particular fluids. The volume fraction  $C_i$  for i-th fluid varies from 0 to 1, where „0” means no i-th fluid in a given point, „1” means that only i-th fluid is present, values between 0 and 1 mean that the interface between the fluids occurs.

The properties of the effective fluid filling the domain are expressed as follows :

$$\rho = C_{\text{air}} \rho_{\text{air}} + C_{\text{water}} \rho_{\text{water}} ; \mu = C_{\text{air}} \mu_{\text{air}} + C_{\text{water}} \mu_{\text{water}}$$

where :

$$C_{\text{air}} + C_{\text{water}} = 1$$

**There is no mixing between the fluids.**

**Additional equations for C are solved.**

**The mesh geometry is fixed.**

The example of the free surface computed with the use of VOF method for the ship model, compared with the experimental one, is shown in Fig.3.

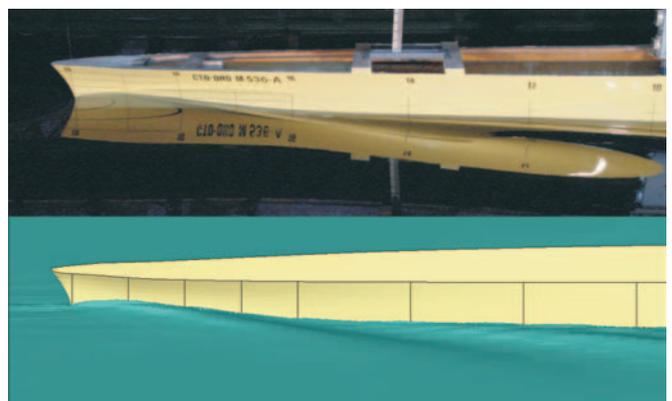


Fig. 3. Comparison of the experimental and computed free surface for the ship model (experiment - by P. Grzybowski, computation - by M. Kraskowski) .

## METHOD FOR COUPLING THE FLOW SOLVER WITH SOLVING THE MOTION EQUATIONS

Let us introduce two coordinate systems :

- the global coordinate system XYZ, moving in the direction of ship motion with the same speed, and
- the local coordinate system xyz connected with the ship's centre of gravity, moving and rotating together with it.

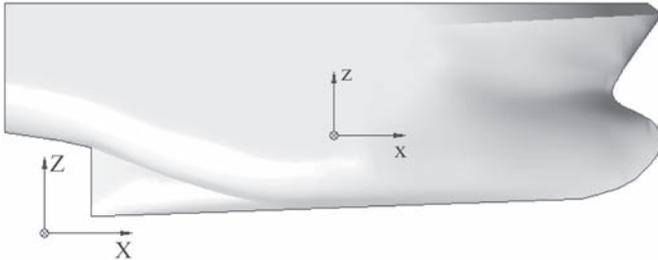


Fig. 4. Coordinate system .

The basic idea of the presented method for wave pattern computations with dynamic trim and sinkage taken into account is that the hull motion directly depends on the forces acting on it and the mesh of control volumes is moving together with the moving hull without relative motion between the mesh nodes. The flow is solved in the global coordinate system and the motion of the control volumes is taken into account in the motion equations. The boundary conditions are also given in the global coordinate system.

The flow solver is programmed to calculate the vertical force and trimming moment acting on the hull (in this case the moment vector points in „y” direction). On the basis of the forces the translational and angular accelerations of the hull are computed in each time step. The accelerations are used to update the translational and angular velocity in each time step and these are used to update the vertical position and trim angle. As mentioned before, the exact time history of motion is of no importance since we are interested in the steady state solution, hence some modifications of the equations can be applied to improve stability of the method.

Therefore the exact algorithm used to evaluate the ship's running attitude can be described as follows :

- ★ Calculate the vertical force  $F_z$  and trimming moment  $M_Y$  in the time step  $t_n$
- ★ Calculate values of the translational acceleration  $a_z$  and rotational one  $\varepsilon_y$  in the time step  $t_n$ , introducing the artificial damping proportional to velocity values :

$$a_z = \frac{F_z - mg}{m} - \alpha V_z \quad ; \quad \varepsilon_y = \frac{M_Y}{I} - \beta \omega_y$$

where :

- m - hull mass
- I - moment of inertia
- g - acceleration of gravity
- $V_z$  - translational velocity
- $\omega_y$  - rotational velocity
- $\alpha$  and  $\beta$  - proportionality factors of positive value.

- ★ Use the acceleration values computed in the previous time step  $t_{n-1}$  to compute the average values and use them as values for the current time step:

$$a_z^n = 0.5(a_z^n + a_z^{n-1}) \quad ; \quad \varepsilon_y^n = 0.5(\varepsilon_y^n + \varepsilon_y^{n-1})$$

- ★ Update the values of the translational velocity  $V_z$  and angular velocity  $\omega_y$  :

$$V_z^n = V_z^{n-1} + a_z^n \cdot \Delta t \cdot D_V \quad ; \quad \omega_y^n = \omega_y^{n-1} + \varepsilon_y^n \cdot \Delta t \cdot D_\omega$$

where :

$D_V$  and  $D_\omega$  - so-called delay factors for the translational and angular velocity, respectively. Values of the delay factors are contained between 0 and 1.

- ★ Update the vertical position and trim angle :

$$Z^n = Z^{n-1} + V_z^n \cdot \Delta t \quad ; \quad \varphi^n = \varphi^{n-1} + \omega_y^n \cdot \Delta t$$

- ★ Go to the next time step.

The modifications of the equations, which improve the stability but make the motion history not exact, are the following : artificial damping and delay of motion. The algorithm in question can be adjusted to simulate the dynamics simply by setting the factors  $\alpha$ ,  $\beta$ ,  $D_V$  and  $D_\omega$  to zero.

## DESCRIPTION OF THE TEST CASE

The method was tested for the fast containership hull of the parameters presented in the table below.

Length b.p.	L	135.25	[m]
Breadth	B	8.45	[m]
Draught	T	4.14	[m]
Block coefficient	$C_B$	0.442	[-]
Prismatic coefficient	$C_P$	0.658	[-]
Waterline coefficient	$C_W$	0.748	[-]

The below given sketch shows the body lines of the hull.

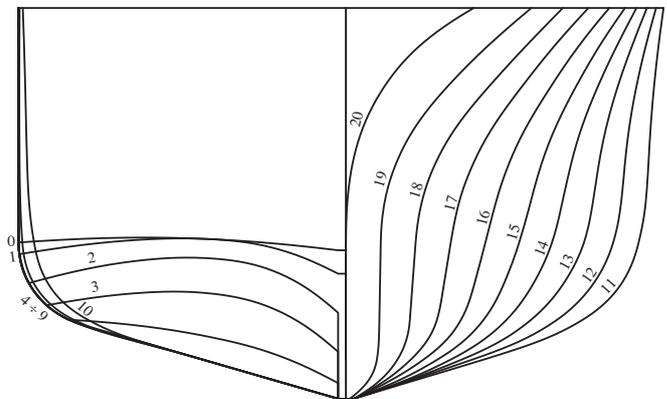


Fig. 5. Body lines of the ship hull used for the test.

The computations were performed for the ship in model scale in order to make direct comparison with the experiment possible. The model scale was equal to [1 : 20.92], hence the model length was 6.47 m.

Four values of model speed were considered. The values are listed in the below given table together with the corresponding values of ship speed and Froude number.

No.	Model speed [m/s]	Ship speed [m/s]	Froude number
1	2.389	10.928	0.3
2	3.186	14.570	0.4
3	3.982	18.213	0.5
4	4.778	21.855	0.6

## MESH GENERATION

Generating the mesh of control volumes is the largest work that the user of CFD software has to do when performing the flow computations. Of course, this process is computer-aided but to obtain a good mesh some knowledge and experience is always required. The basic requirements for the mesh used to solve the ship flow are as follows :

- \* The size of the flow domain divided into the mesh of control volumes should be large enough to avoid the effects of restricted water
- \* If the flow is symmetric, which is the case here, only one half of the hull should be considered with appropriate boundary conditions on the symmetry plane
- \* In regions where the flow variables change rapidly, the size of control volumes (cells) should be small and the size of adjacent cells should be comparable. This is particularly important in the near-wall region where the velocity gradient is high, and in the free-surface region where the volume fraction of water changes rapidly from 0 to 1. It is difficult to specify the required size of cells exactly hence the quality of the mesh should be verified after performing some initial computations. When plotting the flow variables one should obtain smooth contour lines everywhere (this is a very simple, but useful in practice, engineering criterion)
- \* In the regions located far from the region of interest the elements should be large to minimize the computational effort.

The COMET solver requires the mesh to be constructed of hexahedral cells for free-surface computations. Other types of mesh used in CFD are: tetrahedral and polyhedral (polyhedral are cells with arbitrary number of faces). Hexahedral mesh is always recommended to use whenever possible because the discretization of integral equations on hexahedral cells is very natural and such mesh offers good stability and quality of results.

The mesh for the presented computations was generated with the use of ICEM Hexa mesh generator. To generate the mesh the user has to do the following tasks :

- ✦ To define the surfaces bounding the flow domain. The below given sketch shows the edges of the computational domain – the hull is placed in the rectangular block.

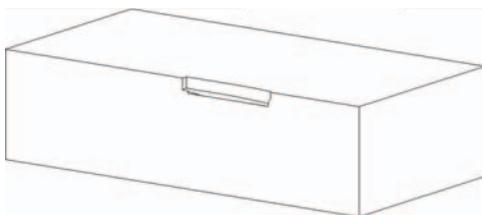


Fig. 6. Edges of the flow domain .

- ✦ To divide the domain space into hexahedral blocks. This task is the most difficult because there is no algorithm to do it and the mesh quality depends mainly on the quality of blocks. Fig.7 shows the edges of the blocks.

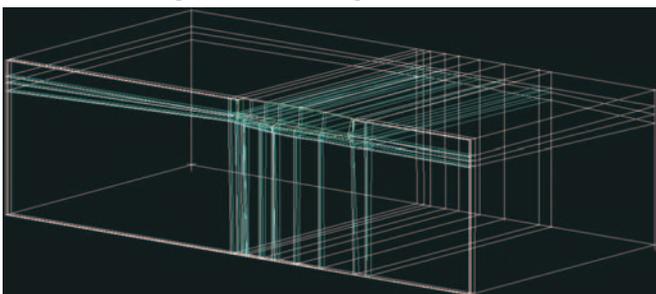


Fig. 7. Flow domain divided into blocks .

- ✦ To divide the blocks into cells. It is simply done by dividing the edges of the blocks. Fig.8 through 10 show the ready mesh.

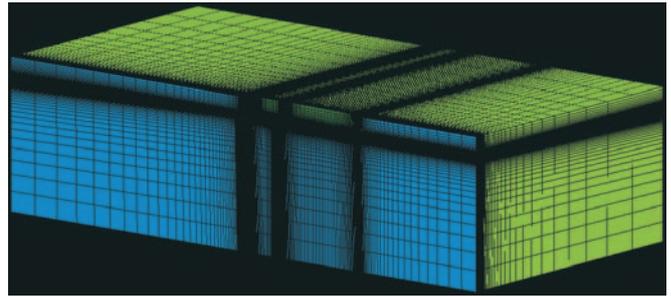


Fig. 8. Mesh of control volumes for entire domain .

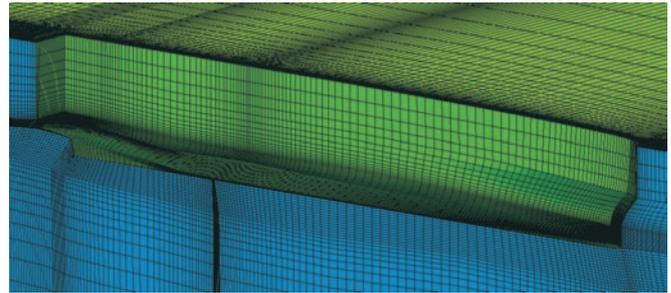


Fig. 9. Mesh of control volumes for hull region .

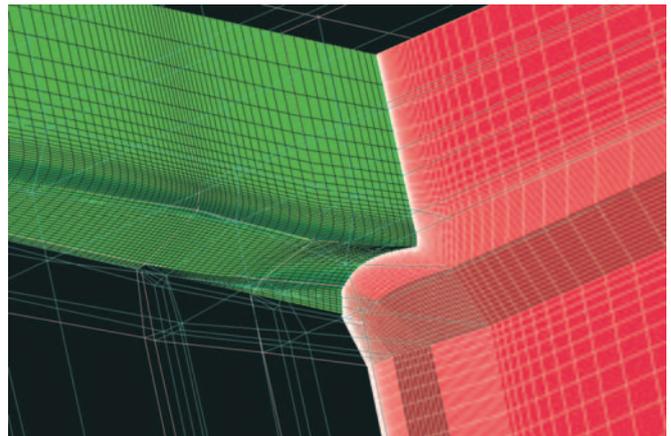


Fig. 10. Mesh details : mesh on the hull surface, section of the mesh interior, edges of the blocks .

## GENERAL PARAMETERS AND PROCEDURE OF THE COMPUTATIONS

The unsteady computations with the use of RANSE method are performed in an iterative manner, and the following levels of iterations can be distinguished :

- ☆ The solution is step-by step advanced with time
- ☆ Iterations are performed to compute the flow for the current time step, i.e. to satisfy the conservation equations (these are called the outer iterations)
- ☆ For each of the outer iterations, iterations are performed to solve the system of algebraic equations (these are called the inner iterations).

In the presented computations the following procedure was used to obtain their convergence :

- ⊛ The uniform flow was taken as the initial condition
- ⊛ The computation for the fixed model was carried out till the convergence of results for the forces acting on the hull were reached. During this computation one outer iteration

per time step was executed. This is the common way of obtaining the steady-state solution, called pseudo time-marching

- When the result convergence for the forces was achieved the motion of the hull was released. The number of outer iterations per time step was increased to 5 and the computation was continued till the result convergence for the hull position were reached.

The figures below show the example history of the motion after releasing the hull translation, translational acceleration and velocity for the Froude number  $F_n = 0.6$ . The acceleration shows the tendency to oscillate, nevertheless the oscillations do not significantly affect the smoothness of the motion.

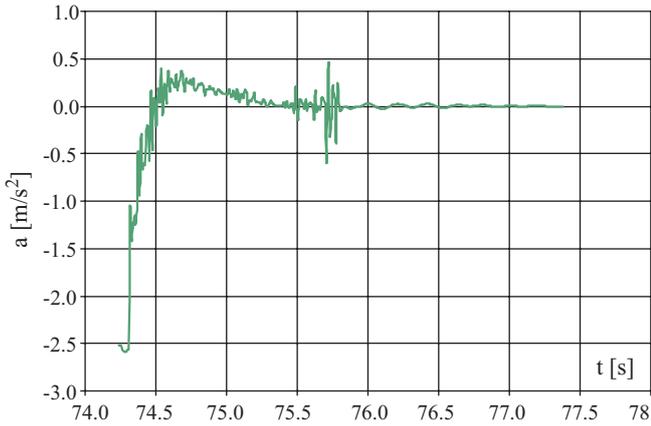


Fig. 11. Time history of the translational acceleration .

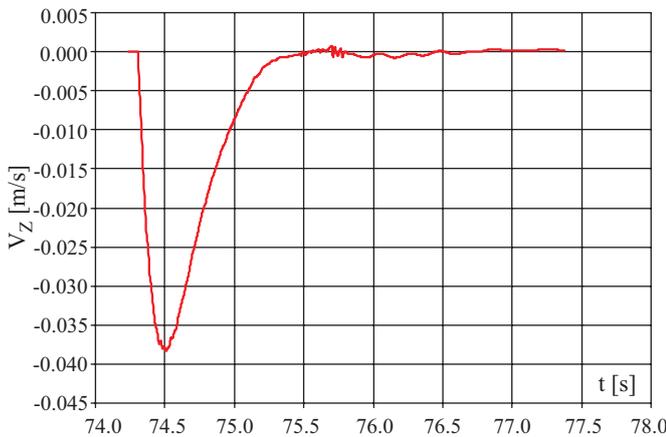


Fig. 12. Time history of the translational velocity .

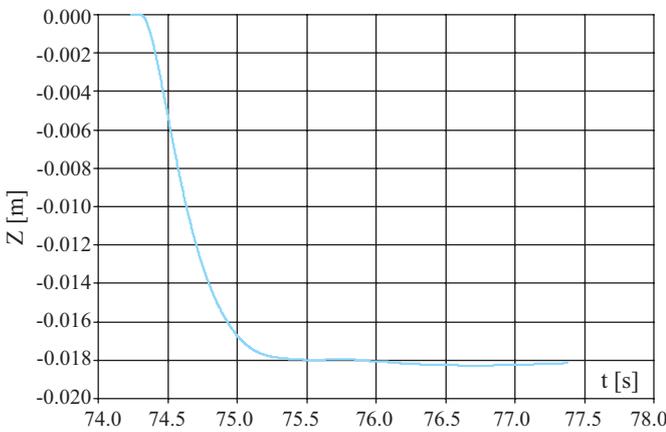


Fig. 13. Time history of the total translation .

## RESULTS

The following results are presented :

- computed running attitude of the hull, defined by the change of the draught (sinkage)  $Z$  and trim angle  $\phi$  (compared with the experimental values)
- wave contours
- wave profiles (compared with the experimental profiles).

Fig.14 and 15 show the computed and measured running attitude of the hull in function of Froude number.

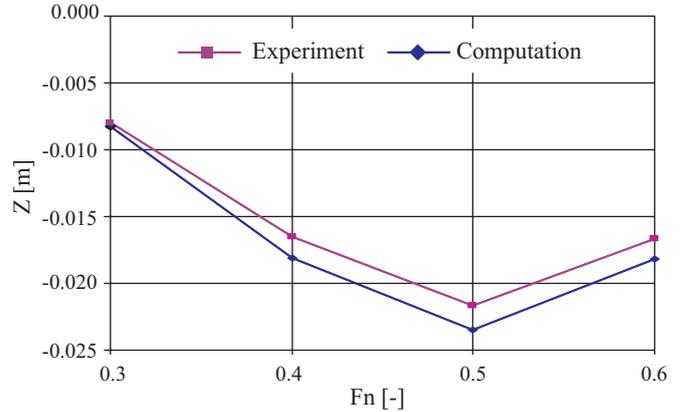


Fig. 14. Computed and measured sinkage .

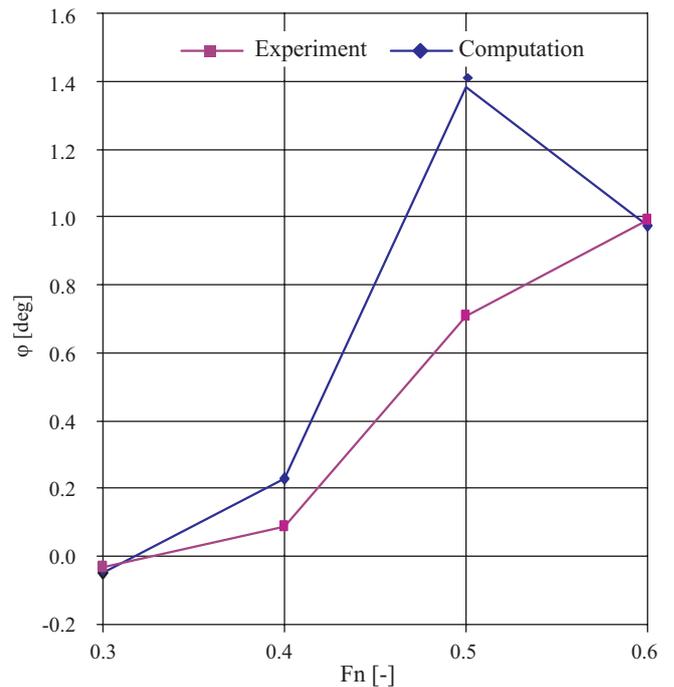


Fig. 15. Computed and measured trim angle .

Fig.16 through 19 show the wave contours corresponding to Froude number values : 0.3, 0.4, 0.5 and 0.6.

Tab.1 presents the wave profiles in the planes parallel to the symmetry plane, located at  $Y=B$  and  $Y=3B$  from the symmetry plane, where  $B$  is the ship breadth. The computed profiles are compared with those measured. Thick lines indicate the location of aft perpendicular (at  $X = 0$  m) and fore perpendicular (at  $X = 6.47$  m).

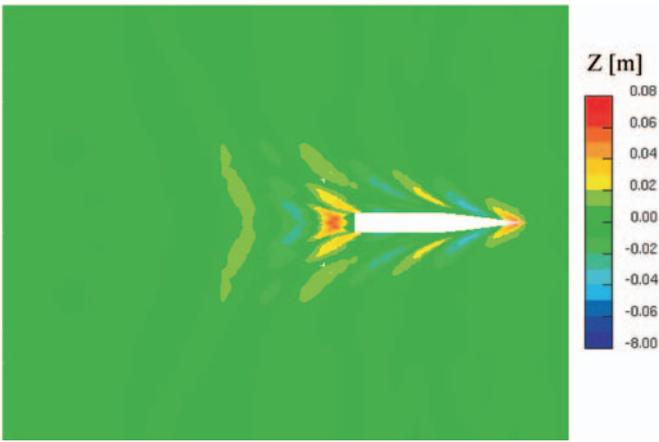


Fig. 16. Wave contour at Froude number  $Fn = 0.3$ .

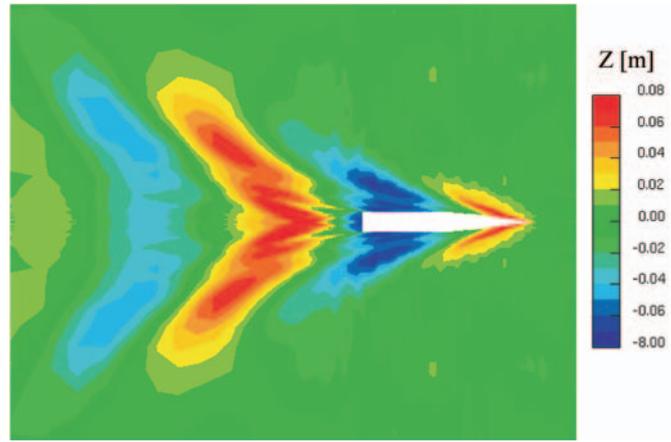


Fig. 18. Wave contour at Froude number  $Fn = 0.5$ .

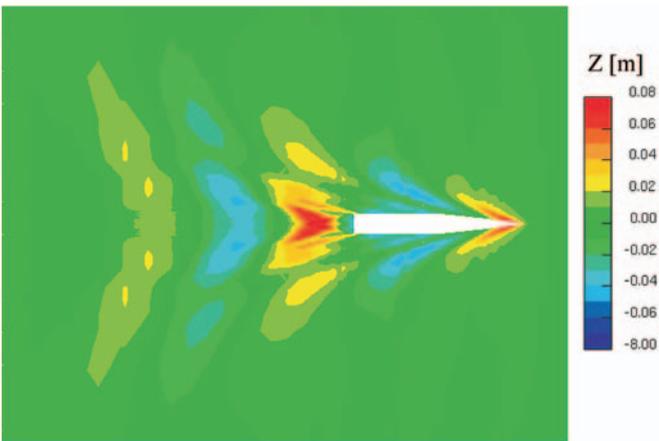


Fig. 17. Wave contour at Froude number  $Fn = 0.4$ .

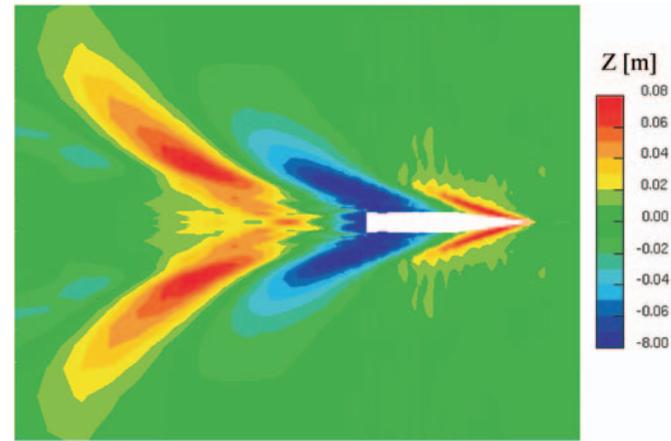
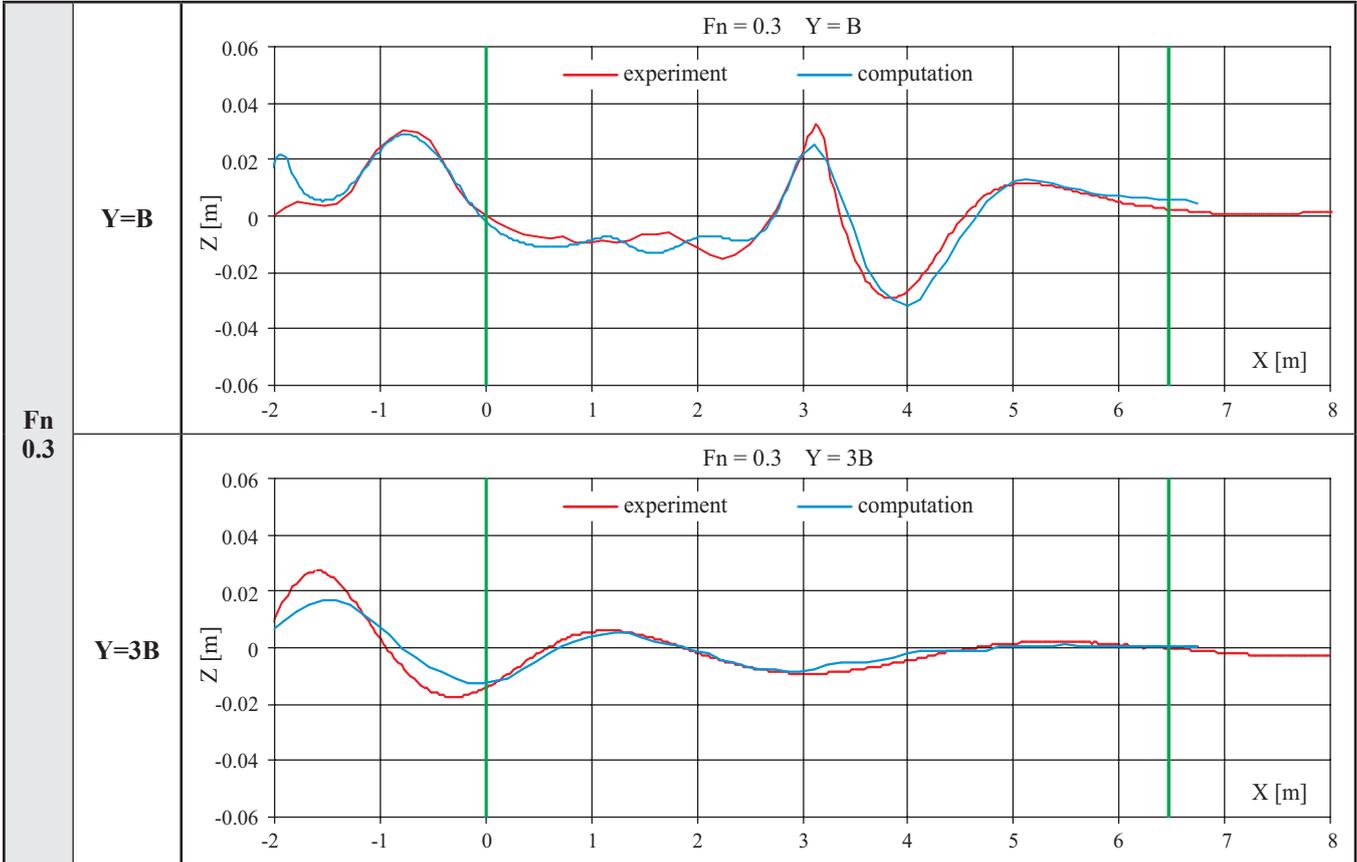
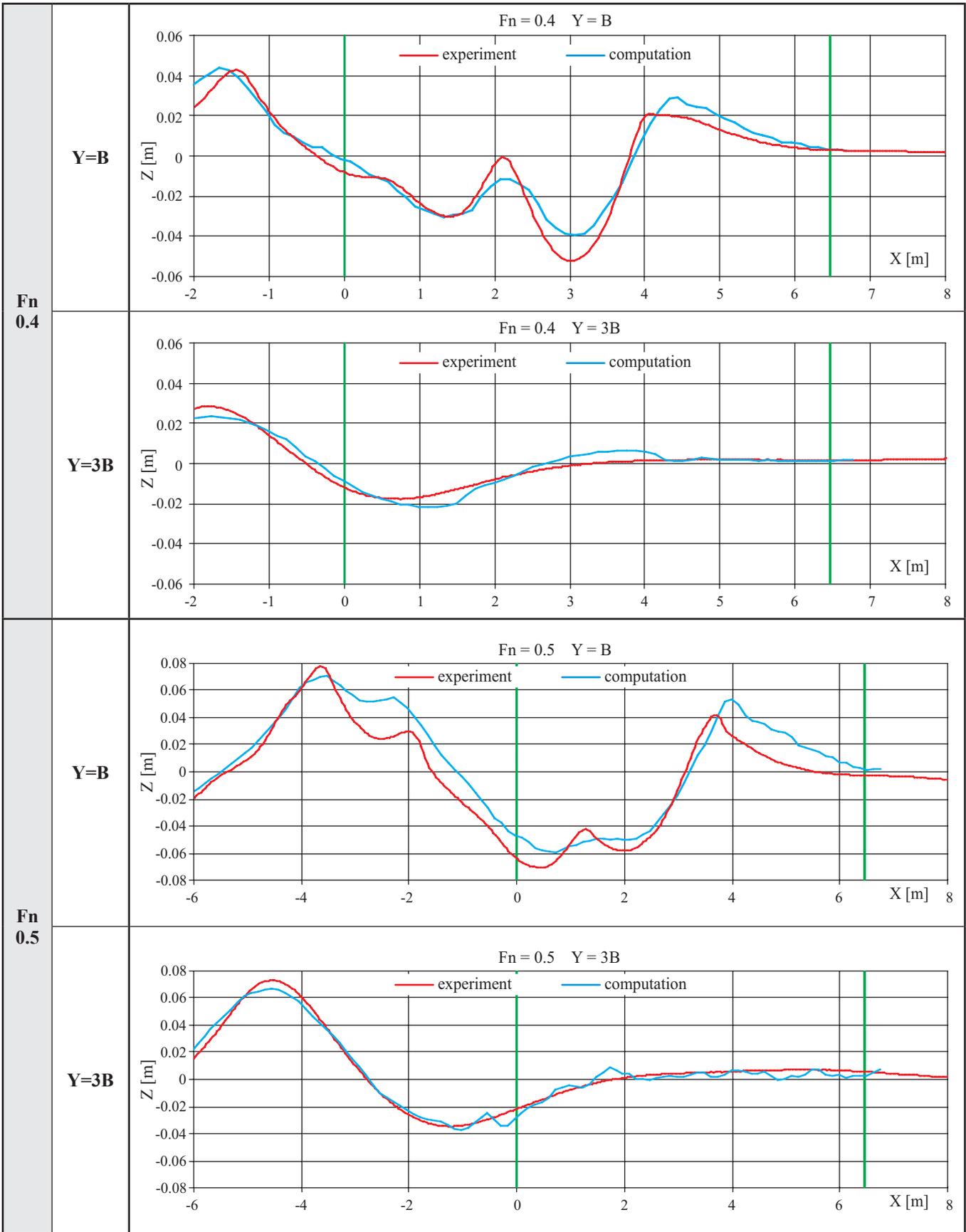
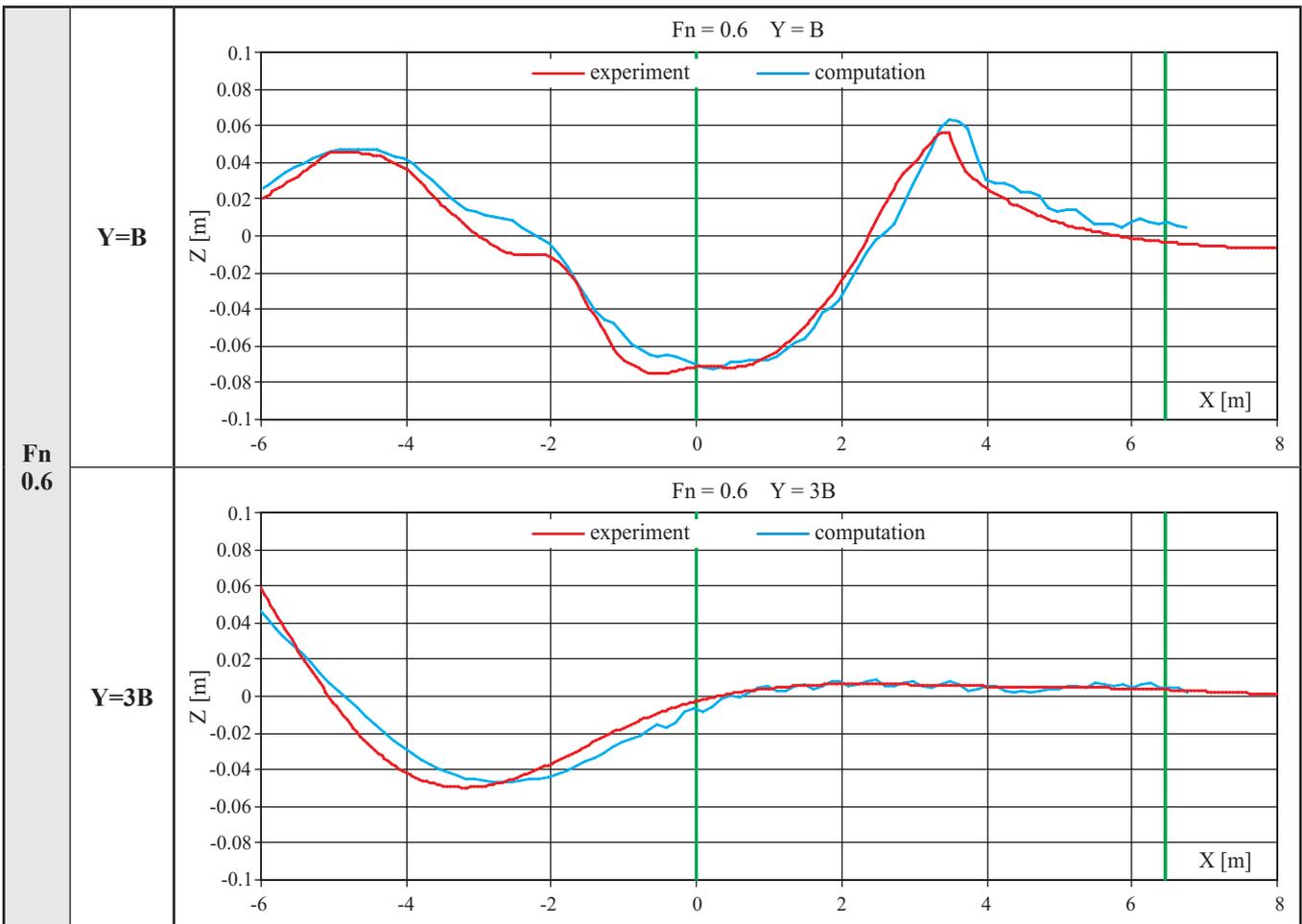


Fig. 19. Wave contour at Froude number  $Fn = 0.6$ .

Tab. 1. Wave profiles in the planes parallel to the symmetry plane







**CONCLUSIONS**

The comparison of the obtained results with the experiment yields the following conclusions :

- The best agreement of the computed and measured ship's running attitude as well as the wave profiles was obtained for extreme values of Froude number considered in the computations, i.e.  $F_n = 0.3$  and  $F_n = 0.6$
- The largest error of the computed running attitude occurred for Froude number  $F_n = 0.5$ . At this value the maximum computed trim angle is observed, while in the experiment the trim angle increases monotonically when the speed increases. The Froude number range between 0.3 and 0.6 seems the most „difficult” with respect to the numerical prediction of the flow since in this range the transition between displacement floating and planing occurs. Nevertheless the predicted wave profiles for  $F_n = 0.4$  and  $F_n = 0.5$  are also in a good agreement with the experiment.
- For  $F_n = 0.5$  and  $F_n = 0.6$  some short, non-physical waves are observed near the bow part of the hull, which results from the mesh geometry influence.

**The final conclusion is that :**

- The proposed method for evaluating the wave pattern with accounting for the dynamic trim and sinkage is robust and accurate enough to estimate the hull quality with respect to the generated wave pattern. It is worth of further validation and development in order to improve the quality of the results.

- The successful attempt on coupling the flow solver with the body motion computations encourages developing the body motion module and using it to simulate dynamic phenomena, e.g. launching. Further challenge is the simulation of hull motion in waves.

**Acknowledgement**

The research presented in this paper has been financially supported by the Polish Ministry of Scientific Research and Information Technology (Grant No. 5T12C 074 24). The author would like to express his gratitude for this support.

**NOMENCLATURE**

- $a_z$  - acceleration in „Z” direction
- $C_i$  - volume fraction of the i-th fluid
- $D_v$  - translational velocity delay factor
- $D_\omega$  - angular velocity delay factor
- $F_n$  - Froude number
- $F_z$  - vertical force
- $g$  - acceleration of gravity
- $I$  - hull moment of inertia
- $m$  - hull mass
- $M_y$  - trimming moment
- $n$  - vector normal to control volume surface
- $p$  - pressure
- $\bar{p}$  - time-averaged pressure
- $q_\Phi$  - source of the quantity  $\Phi$
- $S$  - surface bounding the control volume
- $t$  - time
- $u_i, u_j$  - velocity components (in Cartesian coordinate system)
- $\bar{u}_i, \bar{u}_j$  - time-averaged velocity components

$u_i'$	- velocity fluctuation component
$V$	- velocity vector
$V_Z$	- translational velocity
$x_i, x_j$	- components of location vector
$Z$	- translation in „Z” direction
$\alpha$	- translational motion damping factor
$\beta$	- angular motion damping factor
$\Gamma$	- diffusivity
$\Delta t$	- time step
$\varepsilon_Y$	- angular acceleration
$\mu$	- dynamic viscosity
$\rho$	- density
$\phi$	- trim angle
$\Phi$	- general scalar quantity
$\bar{\Phi}$	- averaged value of general scalar quantity
$\Phi'$	- fluctuation of general scalar quantity
$\omega_Y$	- angular velocity
$\Omega$	- control volume

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## Miscellanea

### Scientific meeting

On 5 December 2005 the plenary meeting of the Marine Technology Unit (acting in the frame of the Transport Technical Means Section, Transport Committee, Polish Academy of Sciences), was held at the Faculty of Maritime Technology (WTM), Szczecin University of Technology.

Two papers prepared by WTM scientific workers, were presented :

- ★ *Model tests of ship fluidal boilers* – by W. Zeńczak
- ★ *Starting the shipboard high-power devices on ships equipped with central hydraulic supply system* – by A. Banaszek

An interesting discussion on both the papers was held after the presentation.

Next, the Unit's members discussed organizational problems concerning its current activity and working plan for the year 2006.

## KONES 2005

On 4-7 September 2005 already  
 31st International Scientific Conference on :

### Internal Combustion Engines

took place at Polanica Zdrój, a health resort at the foot of the Stołowe Mountains in south-west Poland. Institute of Aeronautics, Wrocław University of Technology, and Polish Academy of Sciences were the hosts of the Conference. Its program of a very wide range of topics contained presentation of 96 papers including 6 plenary ones, namely :

- ❖ *Ignition control in the HCCI (Homogenous Charge Compression Ignition) combustion engine system fuelled with methanol-reformed gases* – by Toshio Shudo (Hokkaido University, Japan)
- ❖ *Development of a 125cc two-stroke step-piston engine using a one-dimensional engine code* – by A. A. Aziz, Z. A. Latif, M. F. M. Mohamad, G. L. Ming (University Teknologi, Malaysia)
- ❖ *HCCI with selected standard and alternative fuels : challenges and solutions* – by M. L. Wyszzyński (The University of Birmingham, UK) and H. Xu (Jaguar Cars, Coventry, UK)
- ❖ *Development of a DME (dimethyl ether) fueled heavy-duty engine with lean NOx trap* – by Yoshio Sato (National Traffic Safety and Environment Laboratory, Japan) and Takayuki Tsuchiya (Nissan Diesel Motor Co Ltd, Japan)
- ❖ *OSD clean fuel initiative* – by A. Sandel (US Army RDECOM, USA)
- ❖ *Limits of internal combustion engines efficiency* by J. Macek (Czech Technical University in Prague)

54 papers presented during panel sessions were divided into two topical groups :

**Ecology, Combustion, Thermodynamic Processes, Fuelling** (30 papers)

**Design, Operating, Measurement, Control** (24 papers)

36 remaining papers were topics of a poster session.

It should be stressed that many universities and scientific research centres, both Polish and foreign ones, were interested in active participation in the Conference. Polish authors represented as many as 29 centres among which the greatest number of papers (12 papers each) was prepared by authors from Wrocław University of Technology and Cracow University of Technology. Whereas foreign authors who submitted 18 papers together, represented the scientific research centres from Czech Republic, Lithuania, Japan, Malaysia, Germany, Slovak Republic, Switzerland, United Kingdom and USA.

# A method for determining the decision variables of hazardous zone identification system for ship power plant operator

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Antoni Podsiadło  
Wiesław Tarełko  
Gdynia Maritime University

## ABSTRACT

*In this paper a method is presented of determining – on the basis of information available in the preliminary phase of ship power plant design – the set of hazardous and noxious factors for the operator, as well as of converting them into the set of input variables to a hazardous zone identification system. Basing on the choice of values of determined decision variables, the system's user is able to determine potential hazardous zones for the ship power plant operator. Conversions of the determined factors into the set of the system's input variables were performed by using the knowledge achieved from the side of experts in ship power plant designing and operating.*

**Keywords :** ship power plant, safety, operator, hazardous and noxious factors, hazardous zone, task realization procedures, decision variables.

## INTRODUCTION

One of the possible ways to increase effectiveness of ship power plant designing, including the designing for safety of its operators, is to create tools for aiding designer's efforts, e.g. in the form of computer - aided expert systems.

A system of the kind is under elaboration in Gdynia Maritime University [1]. It consists of two basic modules :

- ❖ the system for identification of hazardous zone for operator realizing his service operations
- ❖ the advisory system for aiding the selection of structural form features of machines and devices being in the hazardous zone.

The concept of the system consists in aiding co-operation between designer and computer at the following allocation of tasks :

- ★ the designer provides appropriate information to the system, basing on an analysis of preliminary design of ship power plant, his knowledge, intuition and experience
- ★ the computer processes the introduced data, calculates indices and performs ranking of power plant constructional units from the point of view of their possibility of creating potential hazards for the operator.

Description of the hazardous zone identification system for ship power plant was presented in [1], and its main elements as well as a way of representing the subject-matter knowledge necessary for computer purposes – in [3].

One of the main tasks in building the system in question is the determination of its decision variables by means of which the system's user is capable of determining potentially hazardous zones for the operator. In this paper a method is pre-

sented for determining – on the basis of information available in the phase of preliminary design of ship power plant – the set of hazardous and noxious factors for the operator, and for converting them into the set of the system's input variables. Main modules of the elaborated method is presented in the form of block diagram in Fig.1.

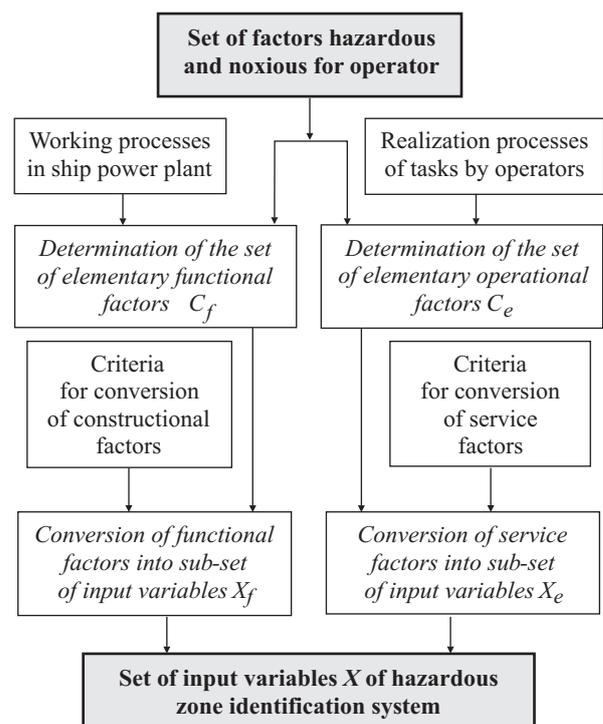


Fig. 1. Main modules of the procedure for determining the input variables of the identification system of hazardous zones in ship power plant .

## FACTORS HAZARDOUS AND NOXIOUS FOR THE OPERATOR

The set of input variables of the system in question consists of the factors hazardous and noxious for the operator realizing his service actions, i.e. the factors creating a hazard understood as a state of working environment, capable of causing an accident or illness of the operator. Such factors may result from all elements of the „man - technical object – environment” system, i.e. in the case in question – consisted of the operator, ship power plant machinery and equipment and their environment. Factors which contribute to building a given kind of hazard for the operator may occur in any element as well as any relation between the elements of such system. The elements of the considered system may be as follows :

- **Man** – together with his all abilities and limitations which depend a.o. on his sea service experience, professional knowledge, skill, memory, habits, professional mentality, motivation, accepted system of merits, psycho-physical state, age
- **Machine** – where special role is played by such factors as : serviceability features, reliability characteristics, ergonomic and functional features, allocation of its units
- **Working space environment** – including : physical and chemical conditions in ship machinery room, spatial features of working place
- **Work organisation environment** – including: organisation of work, inter-personal relations
- **„Man - machine ” relation** – including : position of control unit, accessibility for maintenance and repair work
- **„Man - working space environment ” relation** including: arrangement of machines, man manipulation space
- **„Man - working organisation environment ” relation** including: ship owner policy, crew line-up, crew culture, communication means.

In accordance with the assumptions set in [1], the operator will find himself in a potentially hazardous zone only when he performs a service task.

It is additionally assumed that the operator is qualified in accordance with the International Convention on Standards of Training, Certification and Watch-keeping for Seafarers, he is physically and psychologically fit and his deliberately destructive actions are excluded. Moreover it is assumed that physical, chemical and biological conditions (lighting, noise, temperature etc) comply with the relevant standards, e.g. [5] and [7], all devices operate reliably, and that in ship machinery room mainly physical factors are negatively affecting. Among those factors the following can be numbered a.o.: moving machines and transported objects, elements in motion, falling elements, fluids under pressure, slippery and uneven surfaces, limited spaces, situation of working place respective to a base level (work at high altitudes or in recess), hot or cold surfaces, caustic and noxious substances.

At the taken assumptions, the operator’s hazard level is a function of the factors resulting from operation of machines and devices, access to work place, position of the operator performing a given operation, as well as its kind. Hence the set of the factors was conventionally divided into the two basic groups :

- ❖ the factors  $C_f$  associated with the function of technical objects in realizing the demanded operational processes in a given service state of ship
- ❖ the factors  $C_e$  associated with the kind of operations performed by operators, resulting from realization of demands concerning the service tasks connected with use, maintenance, operation, supply, and safety control.

Obviously, the distinguishment of two groups of factors does not directly make it possible to use them in the computer aided system for identification of hazardous zones in ship machinery room. Therefore they should be converted into the set of input variables  $X$  for the system in question, consisted of two sub-sets [4,6] :

- ⇒  $X_f$  – the set of functional input variables
- ⇒  $X_e$  – the set of service input variables.

## SET OF FUNCTIONAL INPUT VARIABLES

In accordance with the taken assumption, the information available in the phase of preliminary design of power plant, is used in the identification system of zones hazardous for operator in ship machinery room. Such preliminary design mainly concerns functional structure of power plant and makes it possible to identify functions fulfilled by particular constructional units in realising various operational processes. It contains also specification of major machines and devices together with their number and technical characteristics. In this phase, the power plant’s functional structure and constructional structure of its major units (machines and devices) is also known. However, the constructional structure of the entire power plant is not yet determined, hence there is not possible to assess hazards associated with its space environment. Such assessment will be possible in the successive phases of elaboration of power plant documentation, namely in the technical (classification) and working design stages.

Taking into account the scope of information contained in preliminary design, one assumed that the information dealing with operational processes carried out in ship power plant makes it possible to determine the set of functional input variables  $X_f$  for the hazardous zone identification system. To this end, the operational processes realized in ship power plant were divided into the two groups :

- ⊛ the main operational processes dealing with conversion of the energy obtained from fuel combustion into mechanical, electrical and heat energy and their transmission to particular consumers
- ⊛ the auxiliary operational processes realizing the functions of transporting, cleaning, heating, cooling and storing various working media (fresh water, sea water, fuels, oils, air etc.) of determined parameters and quality.

Among the main operational processes the following should be numbered a.o. :

- ❖ the process of conversion of the heat energy obtained from fuel combustion in main engine into mechanical energy for ship propulsion
- ❖ the process of transmission of mechanical energy from main engine to propeller
- ❖ the process of conversion of heat energy obtained from fuel combustion in main engine into mechanical energy for ship propulsion and electric energy produced by shaft electric generator (hang-up)
- ❖ the process of transmission of electric energy from shaft generator to ship electric network
- ❖ the process of transmission of heat energy from exhaust gas to waste-heat boiler
- ❖ the process of transmission heat energy from the water cooling the cylinder liners and heads to waste-heat utilization systems
- ❖ the process of conversion of heat energy obtained from fuel combustion in auxiliary engine (-s) into electric energy produced by generator (-s)
- ❖ the process of transmission of electric energy from stationary electric generators to ship electric network

- ❖ the process of conversion of heat energy obtained from fuel combustion in auxiliary boiler into water vapour heat energy
- ❖ the process of conversion of exhaust gas heat energy into water vapour heat energy in waste-heat boiler
- ❖ the processes of transmission of electric energy from ship electric network to its particular consumers (systems)
- ❖ the process of transmission of heat energy (of steam) from boiler (main steam valve) to particular consumers.

- ☆ the processes for fulfilling the living needs of crew and passengers (sanitary, fresh water, sewage, reefer store and air-conditioning systems, etc.)
- ☆ the processes supporting environmental protection devices (sewage treatment system, bilge water /oil separator, etc.).

Mechanisms of physical state changes of operational processes may be different, but they are always connected with action of several forcing factors.

Among the auxiliary operational processes the following should be numbered a. o. :

- ☆ the processes supporting operation of the energy system, i.e. main and auxiliary engines, boilers and other devices supporting energy supply (lubricating oil, cooling water, fuel, compressed air, exhaust gas systems etc.)
- ☆ the safety ensuring processes (ballast water, bilge water, fire fighting (water, CO<sub>2</sub>, steam etc.) systems

The forcing factors can be divided into two main groups :

- ◆ external , ◆ internal.

Among the external forcing factors are numbered such expected and unexpected environmental impacts onto a given object, as ambient temperature changes, vibrations generated by neighbouring objects, changes of voltage or pressure in supply networks, humidity, dust, human actions, etc.

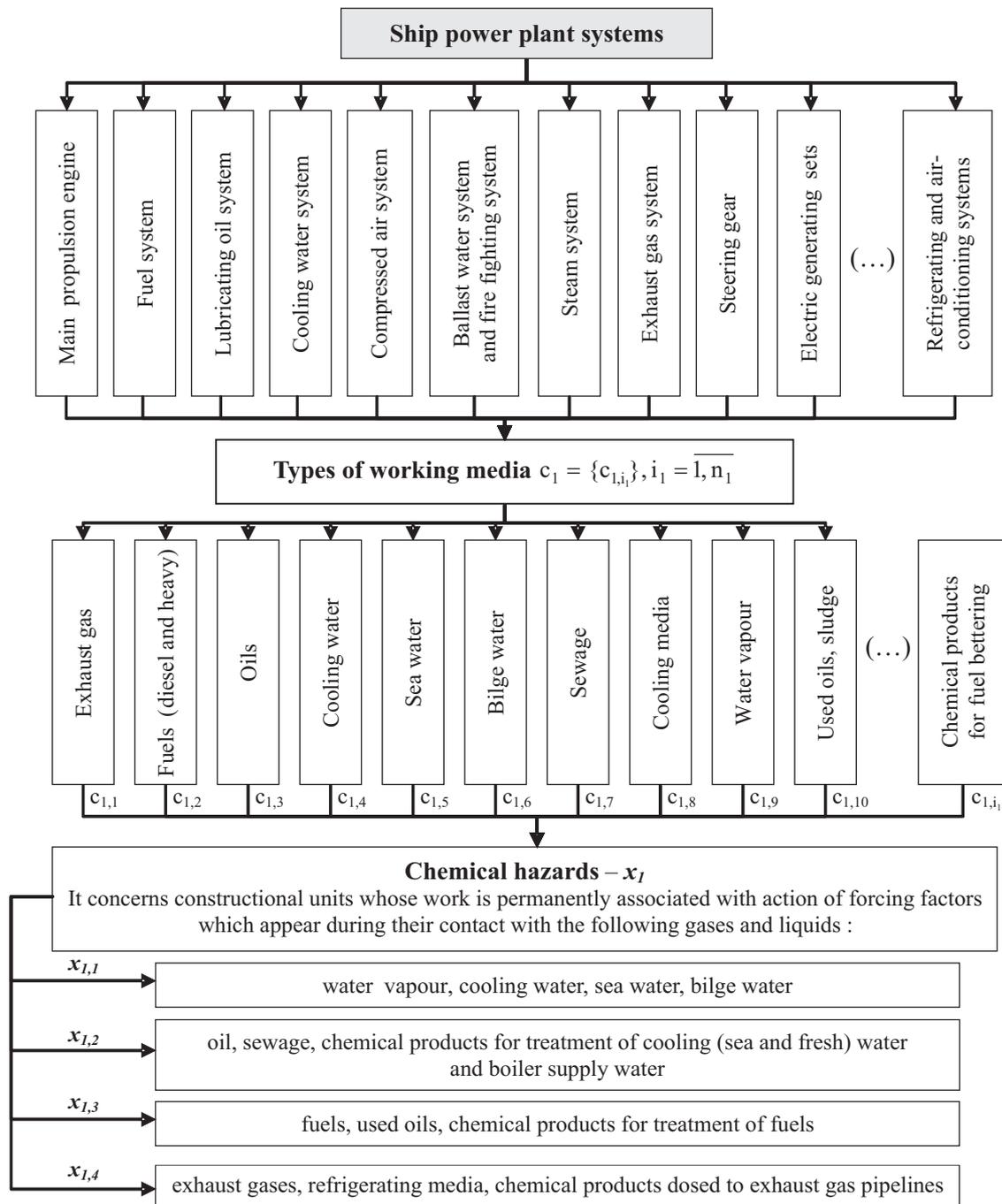


Fig. 2. Classification of chemical hazards

Among the internal forcing factors are numbered the following: load-generated forces, vibrations, actions of working media, etc.

Simultaneous consideration of the sets of external and internal factors occurring in various states of power plant operation, differing to each other by a number and type of realised operational processes, is specially important for assessment of potential hazards to the operator.

To distinguish the set of elementary functional factors  $C_f$ , the decomposition of power plant was performed by increasing the detail consideration minuteness of its functional structure [2]. At the first level of the minuteness its systems were distinguished (Fig.2) and the set was formed of the working media used in them,  $c_1$ , whose chemical composition may expose operator's health to a danger.

In each of the systems, such sub-systems were distinguished, whose analysis made it possible to elaborate the set of values of working media temperatures,  $c_2$ , and pressures,  $c_3$  (Fig.3). And, the set of states of power plant thermal energy

loading,  $c_4$ , was distinguished, depending on a switching-on sequence of the successive main processes, beginning from the power plant stand-by state and ending with its operational states during manoeuvres and sea voyage (Fig.4).

The components (subsystems) distinguished at two first detail minuteness levels are to a large extent common for majority of ship power plants fitted with main combustion engines. Also, a great similarity can be observed at the third level into which the units were distinguished. The units are integral structural parts such as a fuel filter at the inlet of fuel delivery pump, overflow pipeline fitted with check valve, centrifugal separator's delivery pump, boiler fuel daily tank.

For the units the following set of kinds of the operational movements,  $c_5$ , and their components, as well as the set of modes of electric energy supply,  $c_6$ , were distinguished (Fig.5).

Each of the distinguished factors may differently affect occurrence of hazard to operator. Hence it is desirable to assess their significance for hazard generating and to compose

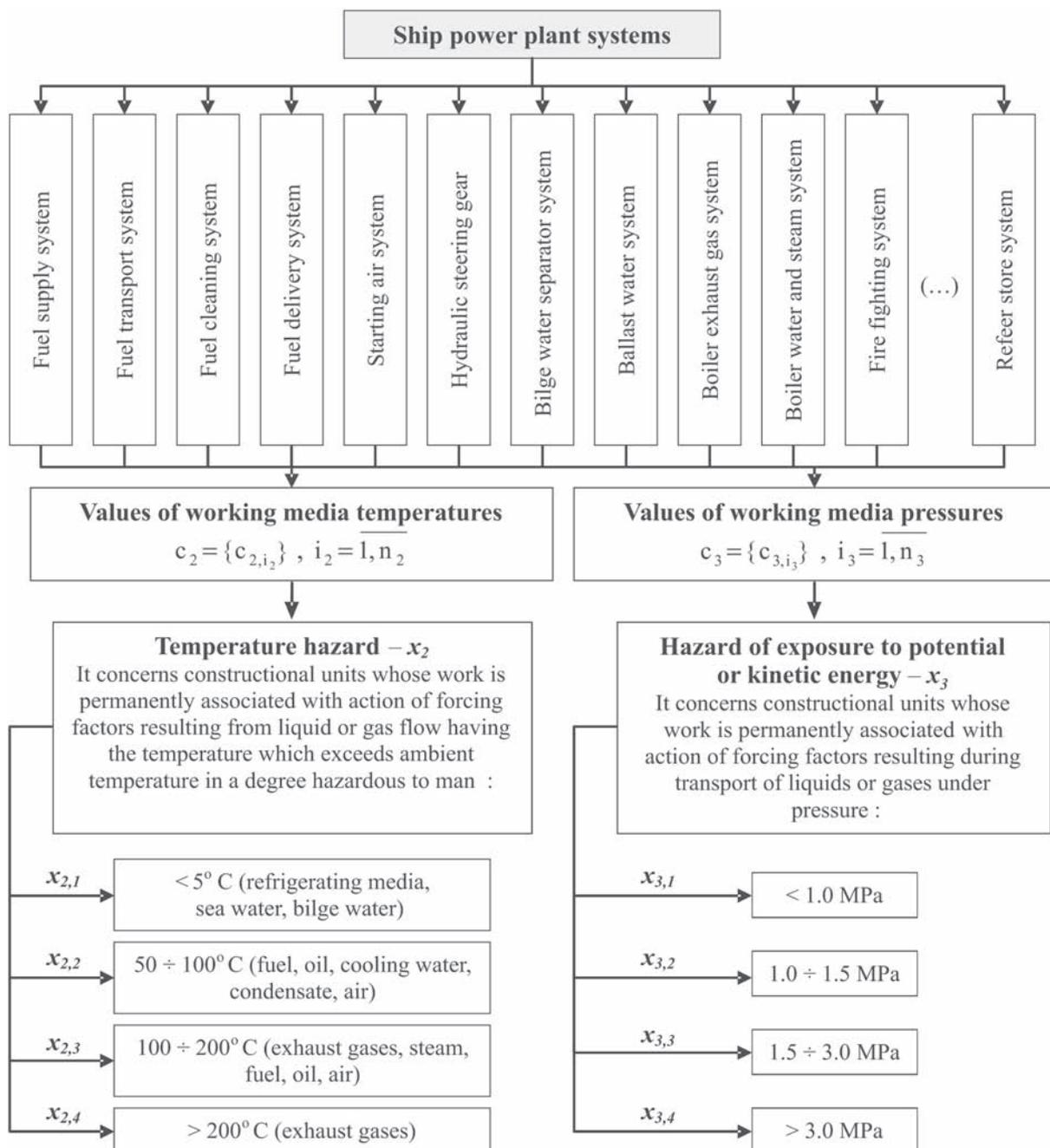


Fig. 3. Classification of hazards associated with working media temperature and pressure .

them into the „entities” containing a subset of similar factors, regarding both their character and effects to operator’s health. The so aggregated factors represent the states of the input functional variables  $X_f$  of the identification system in question. On the basis of opinions expressed by experts – marine engineers, four states successively characterizing higher and higher hazard levels, were assigned to each of the distinguished variables. Names of particular variables and description of their states are presented in Fig. 2 ÷ 5.

### SUBSET OF OPERATIONAL INPUT VARIABLES

In order to determine the subset of elementary factors  $C_e$  associated with kind of operational tasks realized in given internal and external conditions it was assumed that ship power plant should be considered as an anthro-technical system

(Fig. 6) i.e. that consisted of operators, machines and their environment (in the sense of space and organization).

In ship power plant a set of operators (machinery crew either itself or in cooperation with shipyard personnel, producer servicemen etc, or under supervision of various surveyors) realizes given service operations. Safety of the personnel taking part in realization of the operations is exposed to hazards connected with :

- ★ ship operational process (sea voyage, manoeuvres, port stay etc in given external conditions, i.e. climatic zone, weather state)
- ★ power plant running process (number and kinds of operational processes associated with its energy state)
- ★ process of realization of operational tasks by operators (number and kinds of realized tasks depending on a given state of service demands and technical state of power plant).

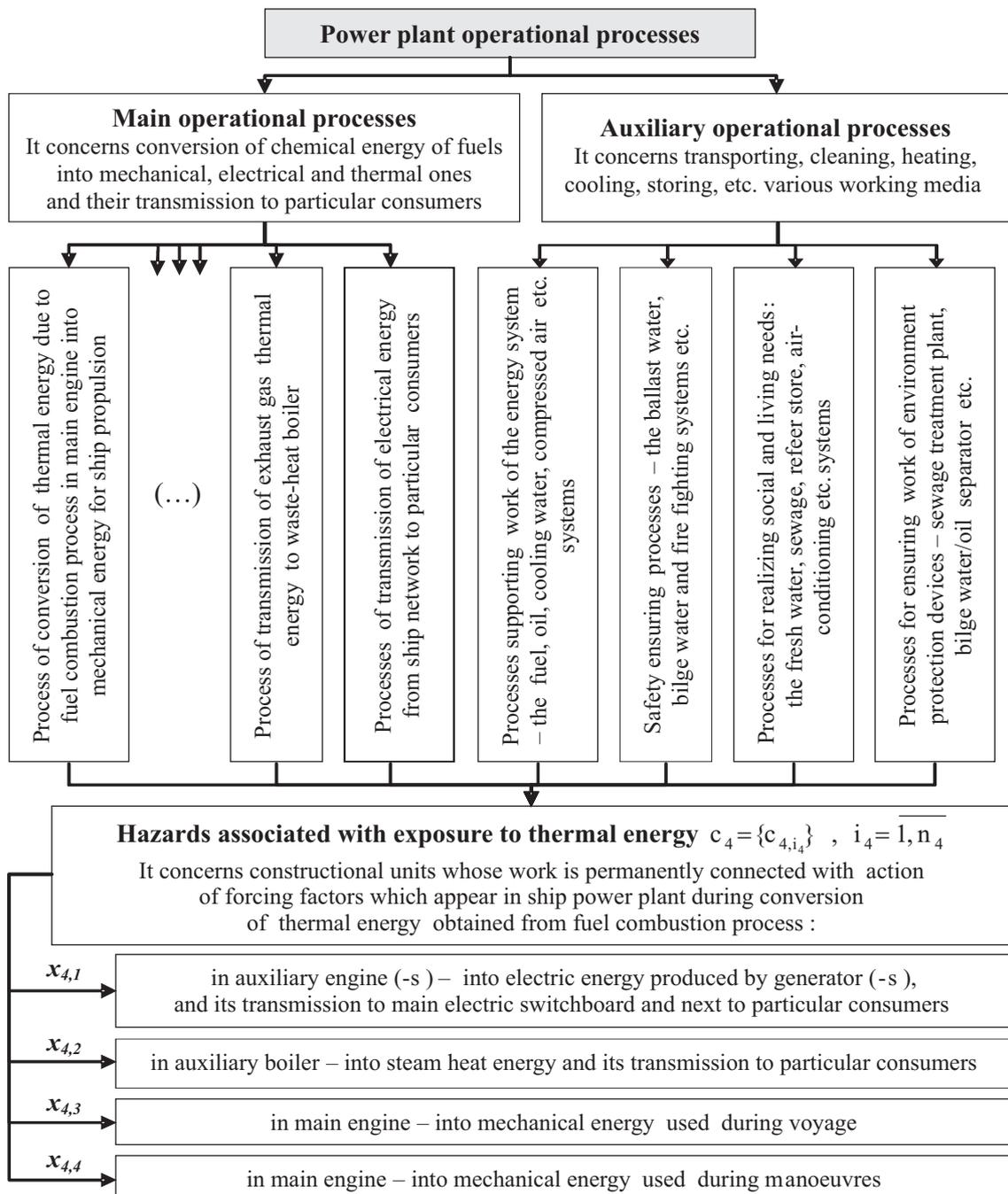


Fig. 4. Classification of hazards resulting from exposure to thermal energy .

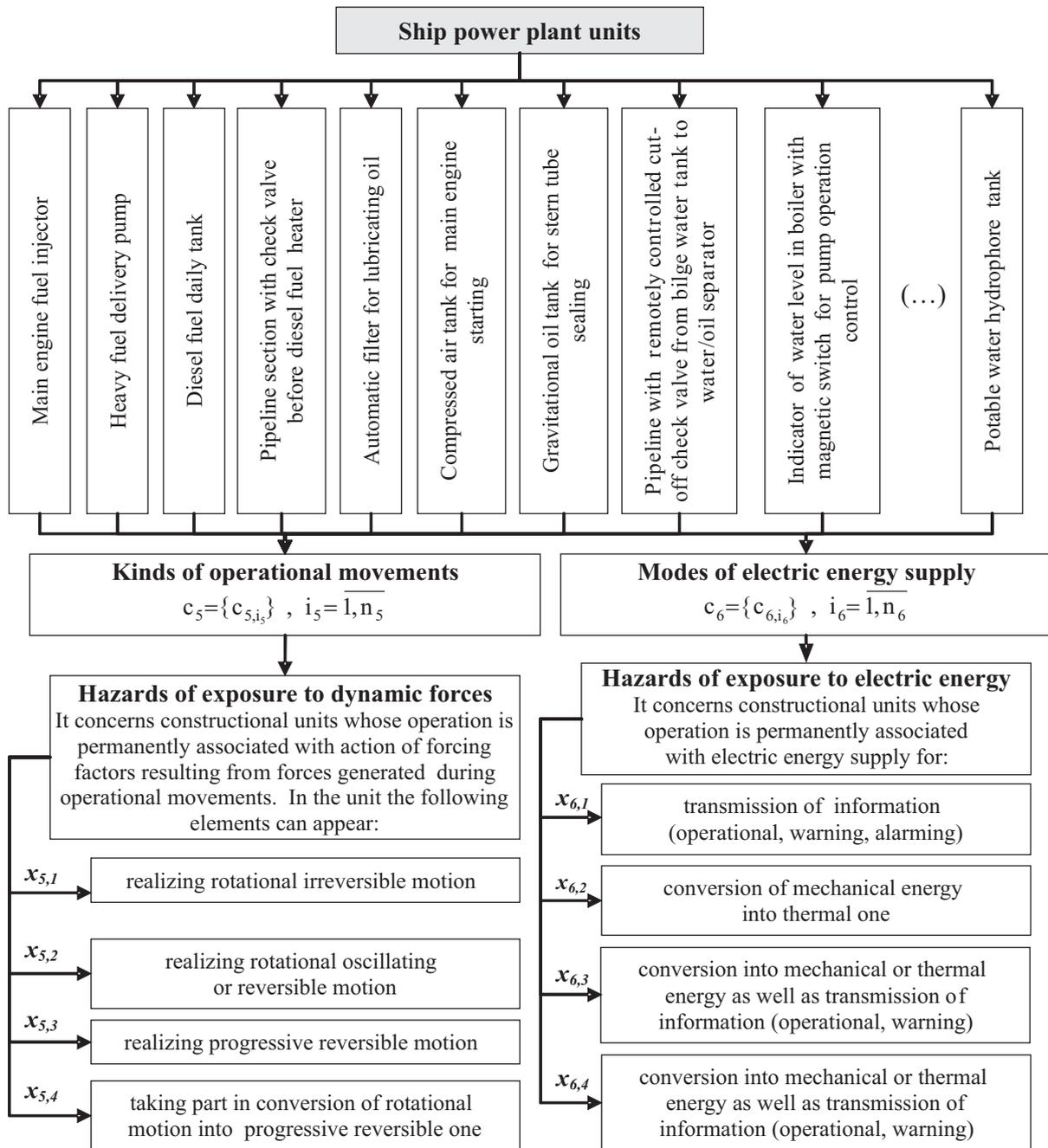


Fig. 5. Classification of hazards resulting from action of dynamic forces and electric energy supply.

In accordance with the classification system used in shipping the four groups of operational tasks are distinguished [5]:

- \* tasks associated with power plant running (use of power plant machines and devices, e.g. main engine preparation to starting-up, fuel transporting to settling tank, starting-up sewage treatment plant, shaft generator switching-off)
- \* tasks associated with power plant maintenance (preventive and repair maintenance, e.g. overhaul of main engine cylinder head, oil sampling, cleaning the water side of air cooler, replacement of fuel filter cartridge)
- \* tasks associated with power plant material procurement (e.g. delivery of fuel and oil, ordering and delivery of spare parts, transport of technical gases, handing - over used parts to regeneration)
- \* tasks associated with control of power plant safety state (e.g. control of insulation state of electric motors, control of emergency lighting, control of signalisation of high level of bilge water).

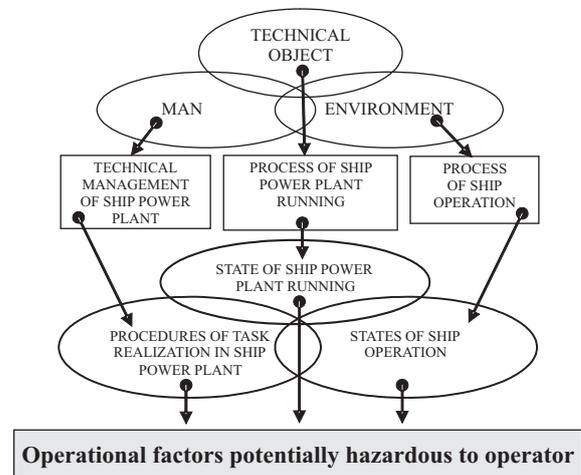


Fig. 6. Kinds of operational factors influencing hazards to ship power plant operator.

The ship power plant management amounts to a decision –making on which of the procedures determining the appropriate ways of realization of operational tasks, are applicable. The procedures contain a.o. sequential list of operations of different detail minuteness levels (number of required persons, duration time, technical parameters). They are based on :

- ✦ technical – operational documentation of ship power plant machines and systems
- ✦ requirements associated with safety at sea and marine environment protection (conventions, codes, rules of classification societies, regulations of maritime administrations, ship owner's regulations etc.)
- ✦ knowledge and professional experience of ship owner's technical department.

To distinguish the set of service operations performed by operator, for each of the ship power plant systems the set of operational procedures, divided into four subsets depending on the kind of relevant task (power plant running, maintenance, material procurement and control of its safety state), was elaborated [1].

The service operation represents a set of operator's elementary actions aimed at realization of a given elementary operational task, e.g. shutting a valve, disassembling a cover, measuring liquid level in a tank, pressure control, switching-off a pump. The operational procedure represents a set of service operations aiming at realization of a given complex operational task, e.g. fuel bunkering, overhaul of a centrifugal purifier, oil replacement in main engine, replacement of a fuel filter cartridge.

The procedures associated with ship power plant running deal with the operational tasks connected with start-up preparation, starting-up, load change, control of running, run supervision, stopping and switching-off its machines, devices and systems, including also tasks associated with coping with emergency situations which may occur in service.

The procedures associated with ship power plant maintenance deal with the operational tasks aimed at maintaining its machines, devices and systems in a physical state deemed to be correct for fulfilling their operational functions or recovering such state.

The procedures associated with ship power plant material procurement deal with the tasks connected with running reasonable economy of materials used for the power plant's operation, such as : fuels, oils, chemical products, spare parts, tools etc.

The procedures associated with ship power plant safety deal with the operational tasks aimed at fulfilling requirements covering its operational safety and marine environment prevention. The requirements for fulfilling the tasks are imposed by the international conventions and rules of classification societies.

The set of the procedures was elaborated by experts- marine engineers on the basis of the functional schematic diagrams and technical data on major machines and devices, available in the preliminary design phase of ship power plant. The kinds of the information used in the designing process of procedures for task realization by operators, are given in Fig.7. The model of the process of task realization by ship power plant operators was presented in [5] as a function mapping the set

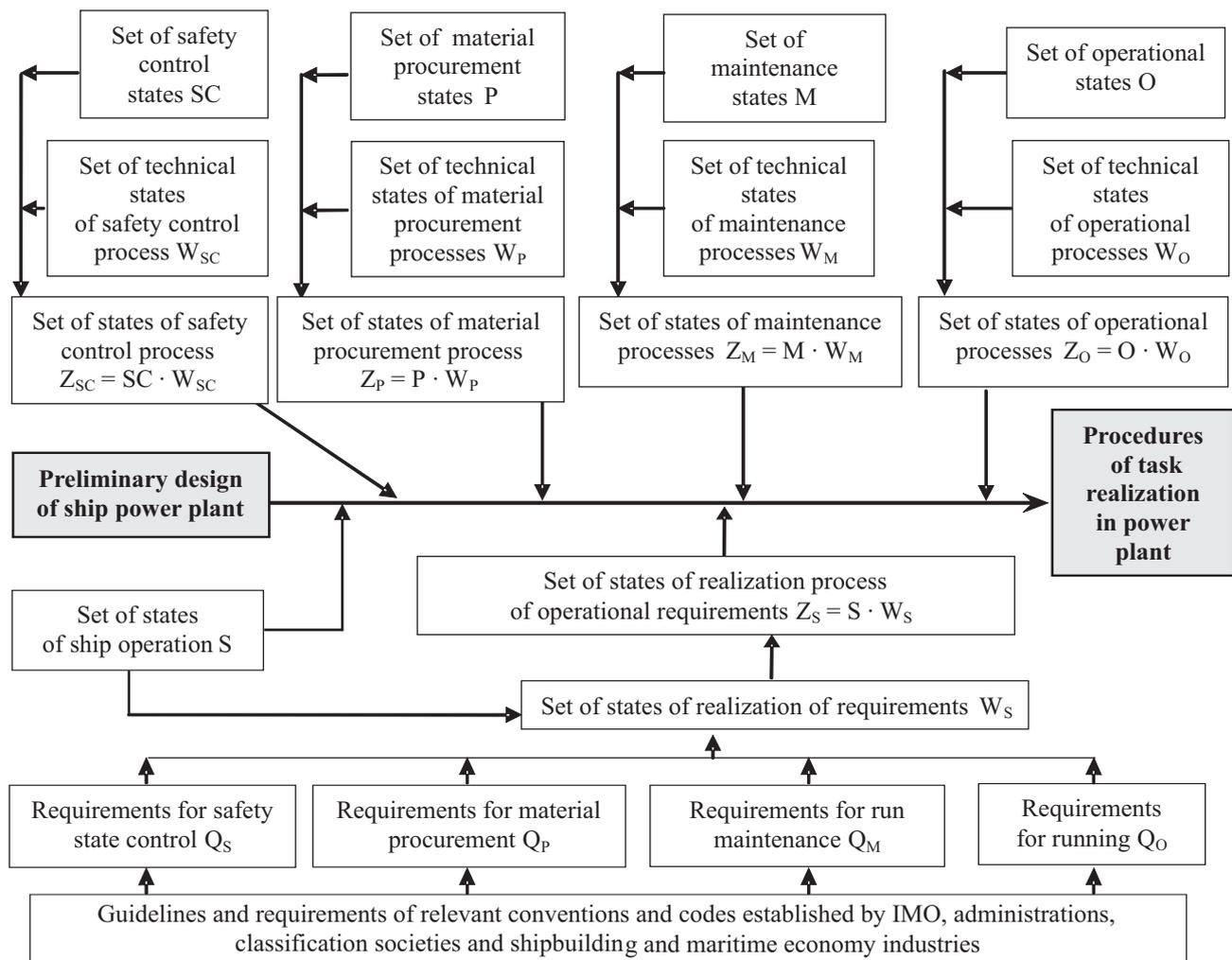


Fig. 7. Kinds of information used in designing process of task realization procedures in ship power plant .

of ship operational states into the set of relations covering possible combinations of the procedures, resulting from the necessity of fulfilment of the requirements dealing with ship power plant running, maintenance, material procurement and control of its safety state.

In elaborating such set of procedures the following remarks should be accounted for :

- ◆ the set of procedures realized in a given ship operation state is strictly connected with the state of realization of operational requirements as well as ship power plant technical state.
- ◆ The states of realization of operational requirements for ship power plant in a given ship operation state have to be described by values of the features contained in the set of the requirements dealing with :
  - ♦ ship running,  $Q_o$  (e.g. ship speed, fuel consumption, electric power loading, serviceability time required for various systems, air parameters for living accommodations)
  - ♦ maintenance,  $Q_M$  (e.g. status of schedule of planned overhauls, status of classification society surveys)
  - ♦ material procurement,  $Q_p$  (e.g. state of amount of fuel, oil, water, spare parts)
  - ♦ safety,  $Q_{sc}$  (e.g. status of schedule of control of : fire fighting systems, marine environment protection systems, ship's security level according to International Ship & Port Facility Security Code – ISPS).
- ◆ In particular ship operation states, various operational processes and associated running procedures are realized by operators in ship power plant. It means that in a given ship operation state occurs a varying number of running states of ship power plant, associated with periodical realization of some operational processes, e.g. transport of fuel, transport and cleaning of bilge water, ventilation and air-conditioning of accommodations. The set of running states covers combinations of the procedures associated

Tab. 1. Input operational variables resulting from kinds of operational procedures

Name of variable	Description of variable	States of variable
Hazard due to realization of operational procedures $x_7$	The variable deals with operational tasks associated with preparation of starting-up, load change, run control, run supervising, stopping, switching-off ship power plant machines and devices	$x_{7,1}$ – procedure is performed only during stand-by (e.g. set of procedures for power plant preparation to manoeuvres or a longer ship stay in a port)
		$x_{7,2}$ – procedure may be performed both during voyage and manoeuvres, as well as stand-by (e.g. fuel transport, servicing ballast and bilge tanks)
		$x_{7,3}$ – procedure is performed only during manoeuvres and/or voyages (e.g. those relating to operation of thruster, shaft generator, procedures for main engine starting-up and stopping)
		$x_{7,4}$ – procedure is associated with run in a failure state (e.g. operation of main engine with one cylinder out of work, various control procedures of local machines and devices in case of break-down of automatic control systems)
Hazard due to realization of maintenance procedures $x_8$	The variable deals with operational tasks associated with realization of scheduled preventive and repair maintenance operations of ship power plant machines and devices	$x_{8,1}$ – procedure may be performed both during voyages and port stays, if not disturbing main engine running (e.g. cleaning the purifiers, oil replacement in air compressor, replacement of bilge pump packing)
		$x_{8,2}$ – procedure may be or is performed during realization of operational process (e.g. oil make-up, filtering cartridge replacement in a double filter, indication of engine cylinders, water washing the turbo-compressor)
		$x_{8,3}$ – during realization of the procedure the main propulsion system cannot operate (e.g. replacement of main engine injector, oil replacement in main transmission gear, cleaning the main engine air cooler)
		$x_{8,4}$ – procedure is aimed at transition to a failure state operation hence the main propulsion system cannot then operate (e.g. disassembling a failed turbo-compressor's rotor, suspension of injection pump's drive, blocking a clutch in working position)
Hazard due to realization of material procurement procedures $x_9$	The variable deals with operational tasks associated with realization of material procurement for power plant machines and devices	$x_{9,1}$ – with transport or storage of spare parts, transport of to-be-repaired objects to and from land-based workshops
		$x_{9,2}$ – with transport and storage of technical gases, chemical products, material stores and tools
		$x_{9,3}$ – with receiving or storing oils, giving-up sludge or oily water
		$x_{9,4}$ – with receiving or storing, and giving-up fuel oils
Hazard due to realization of safety state control procedures $x_{10}$	The variable deals with operational tasks associated with realization of safety state control procedures for ship power plant	$x_{10,1}$ – deals with operation control of devices and systems for marine environment prevention against pollution
		$x_{10,2}$ – deals with operation control of devices and systems aimed at emergency stopping, running or signalisation of extreme states
		$x_{10,3}$ – deals with operation control of devices and systems for fire or water fighting in ship power plant
		$x_{10,4}$ – deals with operation control of emergency supply sources for devices and systems, including emergency electric generating set, objects supplied by it as well as systems cooperating with it

with realization of the operational processes in various ship operation states. Similar situation occurs in considering the maintenance, material procurement and safety state control processes that leads to distinguishing the relevant sets of states of the processes.

- ◆ In practice, in various ship operation states, often the states of partial serviceability or unserviceability of technical objects which take part in realization of particular processes of task realization (constructional units of systems, accommodations, transport devices and ways, tools, measuring instruments, stores, etc) periodically occur. For each of the process, to distinguish elements (units) taking part in its realization as well as their technical states (full serviceability, limited serviceability and unserviceability [9]) is necessary in the course of designing the set of kinds of procedures for a given ship operation state, including the procedures of coping with possible emergency situations.

The process of changing the technical states and that of changing the realization states of the procedures are dependent on each other and hence they must be considered together as the components of a resulting process which can be called the process of task realization by ship power plant operators [5].

In order to determine the subset of input operational variables,  $X_e$ , of the ship power plant hazardous zone identification system, it was assumed that each variable should concern the entire procedure (e.g. the preparation of main engine to work, oil replacement in auxiliary engine, heavy oil bunkering, etc) but not particular service operations (e.g. valve opening, pump switching-on, level checking etc). As a result the impact of the variable concerning the entire procedure will be assigned to the operations contained in it. It means that the level of hazard to the operator performing a given operation depends on the kind of the service task which the procedure deals with. Therefore, four input operational variables, namely the hazards arising from realization of: the running procedures  $x_1$ , maintenance procedures  $x_2$ , material procurement procedures  $x_3$ , safety state control procedures  $x_4$ , were distinguished.

Each of the procedures contained in one of the distinguished variables may differently affect generating the situation hazardous to operator. The hazardous situation occurs only in a determined place of ship power plant in a given operational state, and if the operator performing a given operation within a given procedure, is present there. Ship power plant's operational states are strictly associated with ship's operational states and the fact should be accounted for in determining importance of the procedures for hazard generating.

On the basis of opinions of experts – marine engineers four states successively characterizing higher and higher hazard levels, were assigned. to each of the distinguished operational variables, like in the case of functional variables.

Names of particular variables and description of their states are presented in Tab.1.

## CONCLUSIONS

Basing on the results obtained in the course of the performed considerations dealing with the determination of input variables of the system for identification of hazardous zones within ship power plant, one can offer the following conclusions:

- The determination of functional and operational factors influencing hazards to operator can be performed on the

basis of information contained in the preliminary design of ship power plant and dealing with its functional structure, as well as of the knowledge of operational procedures performed by operator.

- The conversion of the determined factors into the set of input variables of the system can be performed by using to this end the knowledge derived from experts in the field of designing and running the ship power plants.
- Having determined values of the decision variables the system's user can determine zones potentially hazardous for the operator performing service operations in ship power plant.

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# Investigations of motion of the lifeboat lowered from ship's deck

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## ABSTRACT

*A calculation model as well as differential equations of motion of the lifeboat lowered from the deck of the ship under rolling in rough seas, are presented. The equations were numerically integrated. The computer software elaborated on their basis makes it possible to trace instantaneous positions of the lowered lifeboat, calculate velocities and accelerations of its elements, as well as determine forces acting on the boat and persons accommodated in it.*

**Keywords** : ship life-saving equipment, lifeboat launching from ship in waves, mathematical model

## INTRODUCTION

Human life protection and rescue is one of the most important problems with which designers of man-serving objects including first of all sea-going passenger ships must cope.

Introduction of mechanical propulsion to ships contributed to dynamic development of shipbuilding and shipping and various life-saving equipment, however till the tragedy of the Titanic there were no standards and legal regulations concerning the safety of crews and passengers. In 1914 in London the international convention on safety of life at sea was signed and then – as late as in 1929 – ratified by 40 states.

The gradually developing requirements for ship life-saving appliances were set in the successive SOLAS conventions adopted in 1948, 1960, 1974 and 1999.

Systems for evacuation of persons from large passenger ships have evolved from the simple open lifeboats and rafts dropped to water to unsinkable sheltered lifeboats of high strength and fire resistance, launched by means of more-and-more perfect side boat davits.

Fig.1 and 2 show examples of the contemporary davits with lifeboats accommodated in them [1].

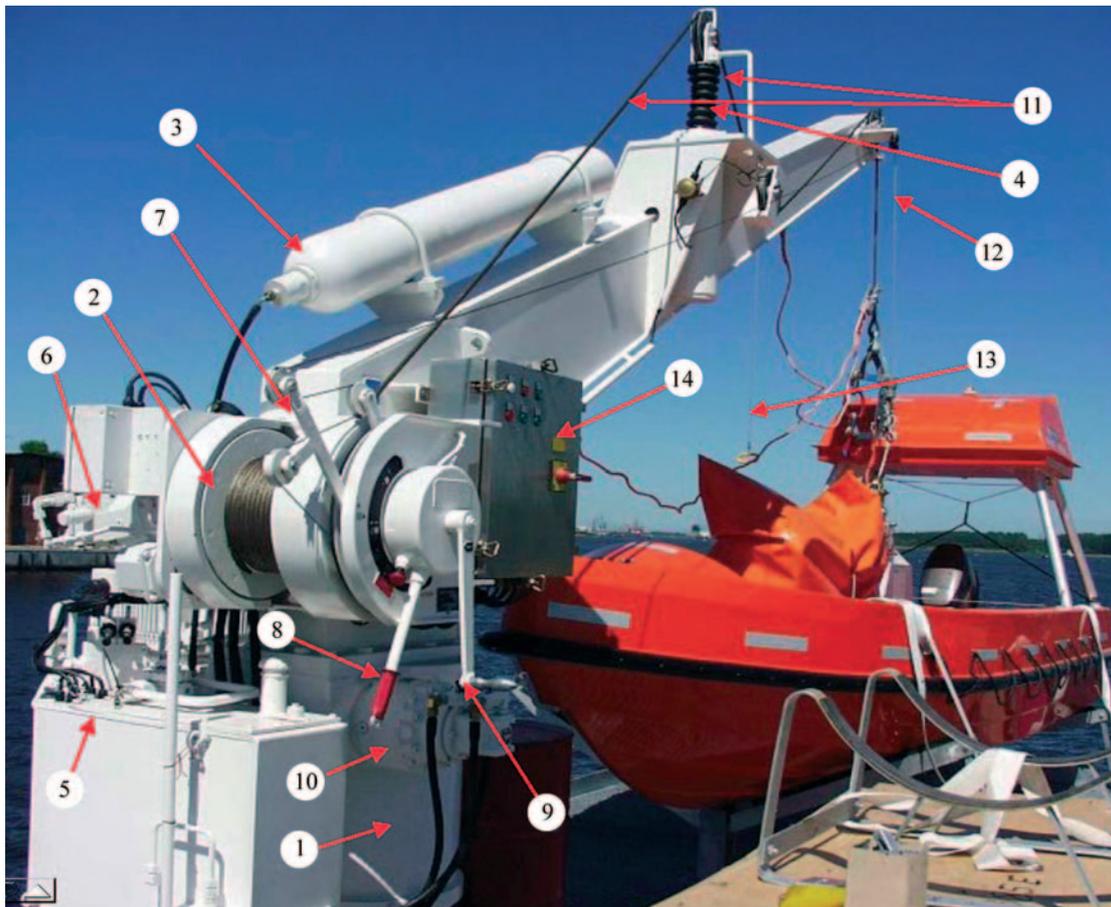
The lowering operation of the lifeboat with persons to water is the most dangerous phase of saving the lives from the ship in emergency at rough sea. The boat lowered from a large height (which is the case especially on large passenger ships) close to the side of rolling ship, often bumps against the ship side. The bumps generate relatively great overloads resulting from change of motion of the boat, that affects the persons located on it. The overloads may lead to a failure of the boat and injuries and even deceases of persons.

For this reason many recognized research centres and leading producers of ship life-saving and rescue equipment search for more and more perfect calculation methods of motion parameters of boat lowered from ship to water in rough

sea conditions. Having a reliable calculation program one can carry out investigations aimed at improving the present design solutions and testing novel devices of the kind.



**Fig. 1.** View of the lifeboat and the luffing jib - traveling davit during defection test .



**Fig. 2.** A slewing davit for fast rescue boat: 1. foundation, 2. boat winch, 3. hydraulic-gas accumulator, 4. shock absorber (damper), 5. electro-hydraulic power unit, 6. hydraulic motor of the winch, 7. lever of the remote control system of the brake, 8. lever of local control of the brake, 9. crank handle of the winch drive, 10. hydraulic motor of the slewing mechanism, 11. wire rope, 12. wire of remote control system of the brake, 13. wire of remote control system of the davit slewing, 14. switchboard.

The problem has been included in the scope of topics of the European SAFECRAFTS project under way in which also Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology, has taken part [2]. In the frame of the project, the SIREHNA, French research centre, using the standard MSC. Adams software, performed a research on the motion of the model boat launched from ship's deck by means of two unextensible ropes hanging from the flexible jibs fixed to ship's deck [3]. Motion of the ship in irregular waves was treated as a random phenomenon.

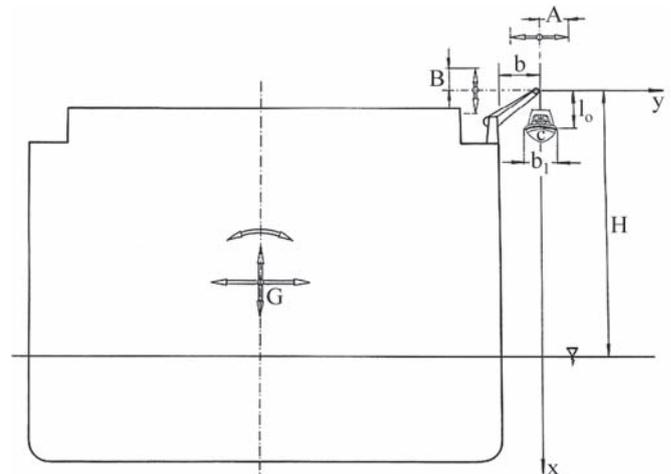
This paper presents some example results of the investigations, performed in Gdańsk University of Technology, of motion of a one-sling model boat launched from the ship in regular waves.

### ASSUMPTIONS OF THE THEORY

It was assumed that the rolling ship and the life boat launched from it is a system of two rigid bodies connected with a flexible davit and elastic rope of variable length. The davit can be fitted with a spring shock absorber with a damper automatically triggered in the case of exceeding the rated force value in the rope. The boat is lowered close to the flat part of ship side parallel to the ship's plane of symmetry. In the motion equations the influence of the boat motion on ship's rolling has been neglected because of the great difference of ship and boat masses.

☆ **The ship's rolling** was represented by a periodic planar motion described by harmonic functions [4]. For describing the boat motion, to know ship's roll period, displacement amplitudes of davit's nock and its coordinates at the initial

instant of boat launching, is necessary. The ship roll period can be determined by using the known methods of ship theory [5]. Values of displacement amplitudes of davit's nock depend on a place of location of the davit on ship's deck (Fig.3).



**Fig. 3.** Location of the boat davit on the ship deck.

☆ **Motion of lowered boat.** To describe the motion of the boat suspended on the rope, was used the model of pendulum consisting the linearly elastic line of variable length and having displacing point of suspension. The motion is realized due to influence of two forces :

- ◆ the gravity force  $mg$ , applied in the boat's mass centre and directed vertically down

- the longitudinal force in the rope,  $N$ , directed along the rope axis and proportional to the elastic displacement of the rope end,  $u$ , measured along the rope beginning from its location in the unloaded state :

$$N = K u$$

The proportionality coefficient  $K$ , called rigidity of elastic constraints of the lowered boat, is discussed below.

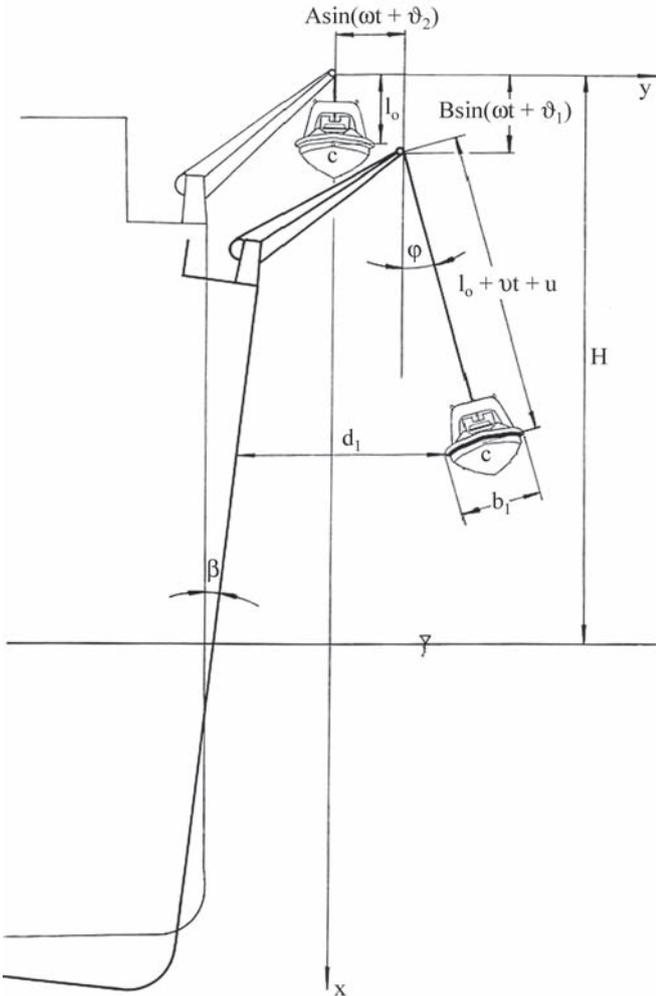


Fig. 4. Model of the motion of the boat launched from the ship rolling in waves.

After introduction of the following notation :

- $A$  – horizontal oscillation amplitude of davit nock [m]
- $b$  – davit nock distance from ship side [m]
- $b_1$  – life boat breadth [m]
- $B$  – vertical oscillation amplitude of davit nock [m]
- $g$  – acceleration of gravity  $9.81 \text{ [m/s}^2\text{]}$
- $l_0$  – davit nock distance from ship's mass centre at the beginning of motion [m]
- $m$  – mass of the boat with embarked persons [kg]
- $t$  – time [s]
- $T$  – period of ship's roll [s]
- $x_0$  – vertical coordinate of davit nock at the beginning of motion [m]
- $y_0$  – horizontal coordinate of davit nock at the beginning of motion [m]
- $v$  – rope running-out speed [m/s]
- $\varphi$  – rope inclination angle from vertical axis [rad]

the boat mass centre coordinates in the Earth - fixed frame of reference,  $Oxy$ , connected with the nock of the davit placed on the motionless ship in still water were described in the following form :

$$x = B \sin(\omega t + \vartheta_1) + (l_0 + vt + u) \cos \varphi$$

$$y = A \sin(\omega t + \vartheta_2) + (l_0 + vt + u) \sin \varphi$$

where :

$$\omega = \frac{2\pi}{T} \text{ [s}^{-1}\text{]}$$

Using Lagrange equations of 2<sup>nd</sup> kind one derived the differential equations of motion of boat mass centre :

$$\ddot{\varphi} = -\frac{1}{l_0 + vt + u} [2(v + \dot{u})\dot{\varphi} + g \sin \varphi + B\omega^2 \sin(\omega t + \vartheta_1) \sin \varphi - A\omega^2 \sin(\omega t + \vartheta_2) \cos \varphi]$$

$$\ddot{u} = g \cos \varphi - \frac{K}{m} u + [(l_0 + vt + u)\dot{\varphi}^2 + B\omega^2 \sin(\omega t + \vartheta_1) \cos \varphi + A\omega^2 \sin(\omega t + \vartheta_2) \sin \varphi]$$

in which the dots over symbols stand for derivatives respective to time. Numerical integration of the equations makes it possible to determine boat's position in an arbitrary instant  $t$ , as well as velocities, accelerations and forces acting on the boat.

- The rigidity of elastic constraints of launched boat** is expressed by the following formula :

$$\frac{1}{K} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3}$$

where :

- $k_1$  – tensile rigidity of rope
- $k_2$  – rigidity of davit
- $k_3$  – equivalent rigidity of shock absorber .

- The tensile rigidity of rope** can be estimated by means of the following formulae :

$$k_1 = \frac{EA}{1.6L}$$

where :

$L = l_z + vt$  – working length of rope in the instant  $t$   
 $E$  – Young modulus

$A = \frac{\pi d^2}{4}$  – rope cross-section area

$d$  – rope diameter,

or :

$$k_1 = \frac{EA_1}{1.3L}$$

where :

$A_1$  – sum of cross-section areas of particular wires of the rope.

- The rigidity of the davit of complex structure** is experimentally determined by measuring the static deflection of its jib's nock,  $f$ , under the load  $P$  :

$$k_2 = \frac{P}{f}$$

If the jib is of the form of uniform cross-section cantilever its rigidity is expressed by the formula :

$$k_2 = \frac{3EJ}{a^3}$$

in which :

- a – cantilever length
- E – modulus of elasticity
- J – moment of inertia of cantilever cross-section area respective to neutral bending axis.

★ **The equivalent rigidity of shock absorber.** If the davit's jib is fitted with a spring shock absorber its equivalent rigidity is defined as follows :

$$k_3 = \frac{k_0}{4 \cos^2 \alpha}$$

where :

- $k_0$  – rigidity of spring of shock absorber
- $\alpha$  – angle of rope inclination respective to spring axis (Fig.5).

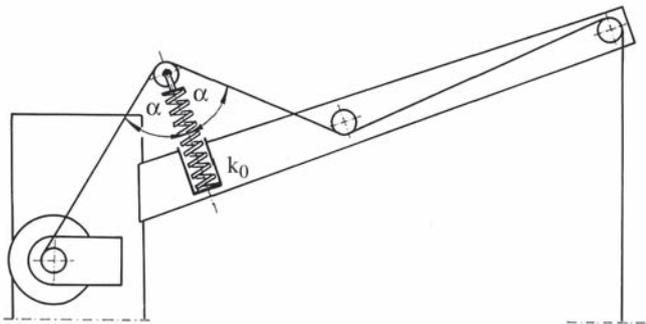


Fig. 5. Schematic diagram of work of shock absorber .

★ **The bump of the boat against ship's side.**

Lifeboat side is fitted with a fender made of an elastic damping material. To describe the bump of the fender against ship's side the linear- elastic collision model with the damping proportional to penetration velocity, was applied. In this case the motion equation is as follows :

$$\delta = \frac{v_0}{\lambda} e^{-ct} \sin(\lambda t)$$

where :

- $\delta$  – depth of penetration (depth of indentation of deformable fender in ship's side) [m]
- $v_0$  – initial velocity of collision [m/s].
- e – Napierian base
- c – damping coefficient of fender [s<sup>-1</sup>]
- t – time interval counted from the instant of contact of the fender and ship side

$$\lambda = \sqrt{\frac{K_0}{m} - c^2}$$

- $K_0$  – rigidity of elastic constraints [N/m]
- m – mass of the boat with accommodated persons .

The coefficients **c** and **K<sub>0</sub>** can be determined experimentally. The rigidity of elastic constraints can be determined by measuring the depth of fender indentation,  $\delta_{st}$ , caused by the horizontal force **F** which presses the boat into ship's side in the state of equilibrium :

$$K_0 = \frac{F}{\delta_{st}}$$

The boat which bumps, through its fender, against the ship's side with the initial relative velocity  $v_0$ , will be bounced out the side with the relative velocity :

$$v_k = -v_0 e^{-c \frac{\pi}{\lambda}}$$

To determine the coefficient **c** it is hence necessary to know amplitudes of the angles of rope inclination from vertical,  $\varphi_0$ ,  $\varphi_k$ , measured before and after the bump of the boat against the vertical motionless ship side, during the free letting-down of the pendulum consisted of the boat suspended on the rope of constant length :

$$c = \sqrt{\frac{\gamma^2 \frac{K_0}{m}}{\pi^2 + \gamma^2}}$$

where :

$$\gamma = \ln \sqrt{\frac{1 - \cos \varphi_0}{1 - \cos \varphi_k}}$$

The duration time of the contact of the boat fender and the ship side is as follows :

$$t_k = \frac{\pi}{\lambda}$$

★ **Example.** The collision run, calculated on the basis of the assumed model, for the lifeboat of the mass **m** = 3000 kg, fitted with the fender of the rigidity **K<sub>0</sub>** = 4.5 · 10<sup>6</sup> [N/m] and damping coefficient **c** = 22 [s<sup>-1</sup>], which bumps against the motionless ship side with the velocity  $v_0$  = 1 [m/s], is presented in Fig.6.

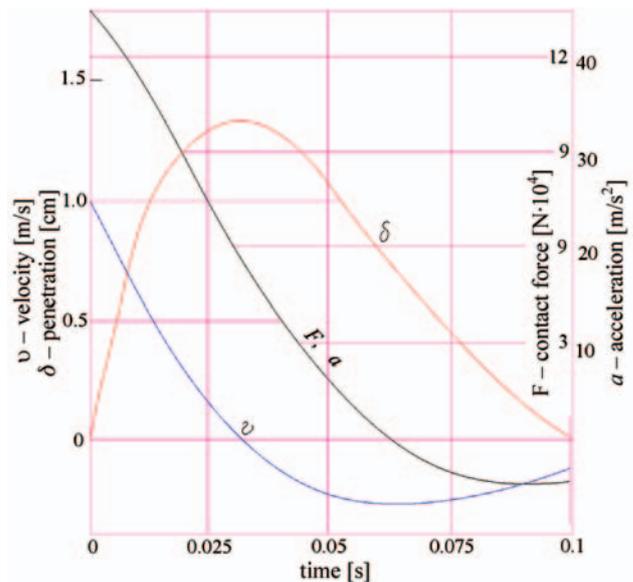


Fig. 6. Collision between the lifeboat and the hull of the vessel .

## COMPUTER SOFTWARE

The computer software based on the described calculation model serves for simulating the motion of the lifeboat suspended on the rope, lowered close to the side of rolling ship. It was written in C++ code and adjusted to operate under Windows system. Integration of the motion equations is performed by using the open step-by-step method [6] in which values of velocities and displacements calculated in the preceding step are the basis for computing the accelerations in the current time step.

The software user has to put in the following numerical data : ship roll period, amplitudes of horizontal and vertical oscillations of the davit nock , distance of the davit nock from the ship side and lifeboat mass centre at the beginning of the motion, davit nock coordinates at the beginning of the motion,

lifeboat mass and breadth, diameter and running-out velocity of the rope, rigidity of the davit and shock absorber spring, as well as lifeboat fender rigidity and damping coefficient.

In the software in question, the simulation of the motion amounts to displaying – on the monitor screen – successive positions of the lifeboat during its letting down. Values of boat mass centre velocity and acceleration, longitudinal force in the rope and deformation of the fender can be read out after termination of the software operation.

## EXAMPLE

### ★ Parameters of the lifeboat and davit

The lifeboat of the mass  $m = 3000$  kg and breadth  $b_1 = 2.3$  m, fitted with the fender of the rigidity  $K_0 = 4.5 \cdot 10^6$  [N/m] and damping coefficient  $c = 22$  [s<sup>-1</sup>], suspended on the steel line of the diameter  $d = 15$  mm, is let down by means of the deformable davit of the rigidity  $k_2 = 1.4$  [MN/m], fitted with the shock absorber with the spring of the rigidity  $k_0 = 500$  [kN/m], whose axis is inclined by the angle  $\alpha = 45^\circ$  respective to the line axis (Fig.5). The shock absorber is automatically triggered when the force in the line exceeds the value  $N = 1$  mg. The distance of the davit nock from the ship side plane :  $b = 4$  m, the line run-out velocity  $v = 0.5$  [m/s], the launching height  $H = 15$  m, the ship roll period  $T = 10$  s.

### ★ Variants of initial conditions for the calculated motion

The davit nock motion described by the equations :

$$x = 1.5 \sin \left( \omega t - \frac{\pi}{2} \right)$$

$$y = 3 \sin \left( \omega t - \frac{\pi}{2} \right)$$

has been caused by the dominating ship rolling motion, and the boat launching starts in the instant when the davit nock takes its highest position :  $x_0 = -1.5$  m ;  $y_0 = -3$  m, (Fig.7A). In the case when the motion is described by the equations :

$$x = 1.5 \sin \left( \omega t + \frac{\pi}{2} \right)$$

$$y = 3 \sin \left( \omega t + \frac{\pi}{2} \right)$$

the starting point of boat launching ( $x_0 = 1.5$  m ;  $y_0 = 3$  m) corresponds to the lowest position of the davit end (Fig.7B).

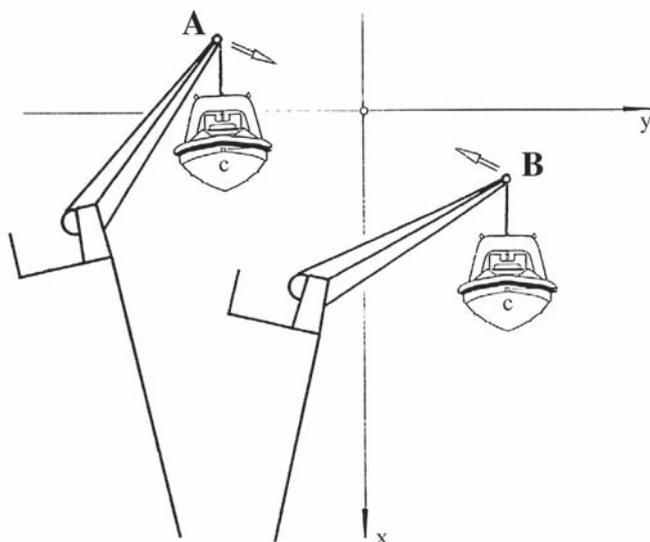


Fig. 7. Two extreme cases of the davit nock position in the instant of start of boat launching .

### ★ Selected results of the calculations

The diagrams shown in Fig.8A and B illustrate changes of the angle  $\phi$  and mass centre acceleration of the lifeboat with persons during its launching, for both the specified cases. In the first case the bump of the boat against the ship side occurred after 14 s, the maximum acceleration due to the bump achieved the value  $a = 14.6$  [m/s<sup>2</sup>] (Fig.8A).

In the case of start of the launching from the lowest position, the lifeboat bumped against the ship side after 18.6 s, and the maximum acceleration exceeded the value  $a = 60$  [m/s<sup>2</sup>] (Fig.8B).

## CONCLUSIONS AND FINAL REMARKS

- In this paper was presented a simple calculation model for describing the motion of the lifeboat launched with the use of one rope from the deck of rolling ship. The main simplifications of the model consist in the assumption that the boat motion is planar, ship rolling harmonic, and the rope axis does not incline from the boat plane of symmetry. However, elasticity of the rope, deformability of the davit as well as a contribution of the shock absorber in mitigating the dynamic overloads were taken into account. The simplicity of the assumed model makes it possible to reveal the most important features of the motion already in the preliminary phase of investigations.
- Despite the assumed simplifications, the results of the calculations based on the proposed model are close to those obtained by means of SAFECRAFTS software [3] in which description of the motion is three-dimensional, and ship rolling is assumed a random phenomenon.
- The computer software based on the assumed model is easy and fast in use. It can help the designer in monitoring the behaviour of the boat and the forces acting on it during its lowering or lifting from water. It makes it possible also to investigate the influence of both technical parameters of the appliance and environmental and initial conditions on the boat's motion and loading.
- The elaborated software may also serve for verification of calculations based on other models.
- The presented example results clearly show to which extent an instantaneous position from which the boat lowering starts as well as a place in which the davit is located on the ship's deck can influence course of the motion even in the same sea conditions. To influence number of bumps of the boat against ship side and to decrease bumping force even by several times is possible by an appropriate choice of the starting instant and position of the boat lowering.
- The applied theory may be easily generalized to arbitrary periodical davit nock motions as any periodical function can be developed into Fourier series fast convergent in the case of using it for description of ship motion. In the above presented differential equations of boat motion will then appear additional terms of the same structure as that of the already existing end terms representing the first harmonics.
- Influence of the inflection of rope axis from boat's plane of symmetry, longitudinal displacements of the boat as well as non-harmonic ship rolling – not accounted for in the presented model – on motion of the boat and magnitude of the forces inducing the motion, will be assessed in the course of further analyses.

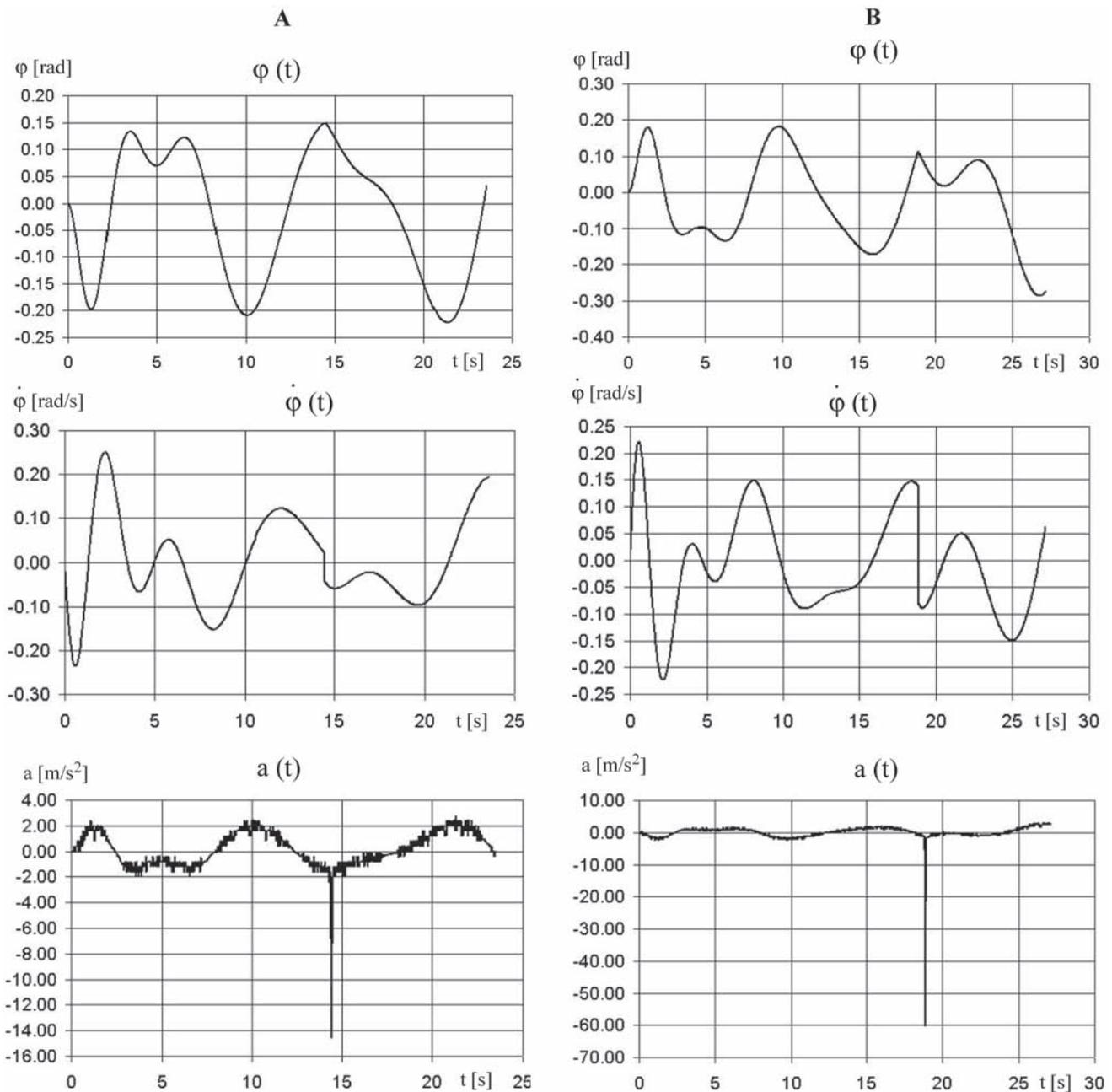


Fig. 8. The calculated runs of changes of the angle and angular velocity of inclination of the line with the lifeboat suspended on it, as well as the boat mass centre acceleration in the lateral direction respective to the ship side, in function of time, for two investigated cases of start of the launching process.

#### NOMENCLATURE

a	– cantilever length[m], maximum acceleration due to bump [m/s <sup>2</sup> ]	$k_0$	– rigidity of shock absorber spring [N/m]
A	– horizontal oscillation amplitude of davit nock [m], rope cross-section area [m <sup>2</sup> ]	$k_1$	– tensile rigidity of rope [N/m]
$A_1$	– sum of cross-section areas of particular wires of the rope [m <sup>2</sup> ]	$k_2$	– rigidity of davit [N/m]
b	– davit nock distance from ship side [m]	$k_3$	– equivalent rigidity of shock absorber [N/m]
$b_1$	– life boat breadth [m]	K	– rigidity of elastic constraints of the lowered boat [N/m]
B	– vertical oscillation amplitude of davit nock [m]	$K_0$	– rigidity of elastic constraints [N/m]
c	– damping coefficient of fender [s <sup>-1</sup> ]	$l_0$	– davit nock distance from ship's mass centre at the beginning of motion [m]
d	– rope diameter [m]	L	– total working length of rope [m]
e	– Napierian base	$L_z$	– initial working length of rope [m]
E	– Young modulus [N/m <sup>2</sup> ]	m	– mass of the boat with embarked persons [kg]
f	– static deflection of davit jib's nock under rated load [m]	N	– force in rope [N]
F	– force pressing the lifeboat into the ship side in state of equilibrium [N]	t	– time [s]
g	– acceleration of gravity 9.81 [m/s <sup>2</sup> ]	$t_k$	– duration time of contact of the boat fender and ship side [s]
H	– lifeboat launching height [m]	$T$	– period of ship's roll [s]
J	– moment of inertia of cantilever cross-section area respective to neutral bending axis [m <sup>4</sup> ]	u	– translation of the end of rope [m]
		x	– vertical coordinate [m]
		$x_0$	– vertical coordinate of davit nock at the beginning of motion [m]
		y	– horizontal coordinate perpendicular to ship plane of symmetry [m]

- $y_0$  – horizontal coordinate of davit nock at the beginning of motion [m]
- $\alpha$  – angle of rope inclination respective to spring axis [rad]
- $\delta$  – depth of indentation of deformable fender into ship's side [m]
- $\delta_{st}$  – depth of fender indentation caused by the horizontal force  $F$  [m]
- $\varphi$  – rope inclination angle from vertical axis [rad]
- $\varphi_0, \varphi_k$  – amplitude of the angles of rope inclination from the vertical, measured before and after the bump of the boat against the ship side, respectively [rad]
- $v$  – rope running-out speed [m/s]
- $v_0$  – initial velocity of collision (bump) [m/s]
- $v_k$  – relative velocity of the lifeboat bounced out of the ship side [m/s]
- $\omega$  – ship roll angular velocity [ $s^{-1}$ ]

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## Miscellanea

### ZTM Marine Technology Unit

On 19 January 2006 the first – in – the - year plenary meeting of the Marine Technology Unit (acting in the frame of the Transport Technical Means Section, Transport Committee, Polish Academy of Sciences), was held in Gdynia; it was hosted by Electrical and Mechanical Faculty of Polish Naval University of Gdynia.

During the scientific part of the meeting were presented two papers prepared by the scientific workers of the University :

- ❖ *Choice of repair technology for screw propellers, depending on distribution their strength (mechanical) properties* – by K. Rogowski
- ❖ *Choice of water content in water-fuel emulsion delivered to cylinders, depending on service process state of ship diesel engine* – by R. Zdraż

After the presentation an interesting discussion on both the papers developed.

In the organizational part of the meeting Prof. J. Girtler (Gdańsk University of Technology) presented the report on the Unit's activity in 2005 and submitted proposals to the program of the Unit's activities in 2006. Problems of organization of scientific conferences on design and operation of ship power plants were also discussed.

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On 12-14 September 2005

7th Domestic Scientific Technical Conference on :

### *Diagnostics of Industrial Processes*

was held in Rajgród, a small town  
in the lake region of north-eastern Poland.

It was arranged under the auspices of the Committee on Automation and Robotics, Polish Academy of Sciences, with the Institute of Automation and Robotics, Faculty of Mechatronics, Warsaw University of Technology as its main organizer. 3 plenary papers and 110 technical papers were prepared for the Conference, and presented during 15 topical sessions, as follows :

- ❖ **Diagnostic methods** (12 papers)
- ❖ **Analytical methods** (7 papers)
- ❖ **Artificial intelligence – fuzzy logics** (7 papers)
- ❖ **Artificial intelligence – neural networks** (6 papers)
- ❖ **Artificial intelligence – genetic algorithms** (6 papers)
- ❖ **Knowledge engineering** (6 papers)
- ❖ **Diagnostic systems** (12 papers)
- ❖ **Industrial applications** (12 papers)
- ❖ **Diagnostics of mechanical devices** (7 papers)
- ❖ **Diagnostics of automation systems** (6 papers)
- ❖ **Failure-proof systems** (7 papers)
- ❖ **Safety and diagnostics of computers** (5 papers)
- ❖ **Vision methods** (6 papers)
- ❖ **Selected problems** (7 papers)
- ❖ **Medical applications** (4 papers)

Authors of the papers represented 26 universities, scientific institutes and research centres including 4 from : Germany, Spain, Belarus and United Kingdom. Representatives of Warsaw University of Technology, Silesian University of Technology, Gdańsk University of Technology, University of Zielona Góra and Metallurgy and Mining Academy gave the greatest contribution to the Conference program, presenting 23, 15, 14, 13 and 11 papers, respectively.

The Conference's proceedings were published in the special issue (September 2005) of *POMIARY, AUTOMATYKA, KONTROLA*, a scientific technical monthly.