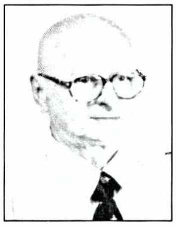

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Performance - - oriented intact stability criteria for ships - - prospects and encountered problems

SUMMARY

In the paper problems that are encountered in the attempts to develop performance-oriented intact stability criteria for ships, are discussed.

Probabilistic approach to stability criteria is advocated but difficulties with its application are stressed including problems in calculation of the probability of capsizing, seaway climatic criteria, hazards identification, capsizing scenarios and acceptable level of risk.

INTRODUCTION

Development of intact stability criteria has long history. The first international stability criteria were adopted by IMO in 1968. In 1993 the Intact Stability Code (IS Code) comprising intact stability requirements for all types of ships was adopted by resolution A.749(18). The IS Code incorporated stability criteria and requirements which were developed for various types of ships up to 1993. However in early seventies the idea of development of the so-called „rational" criteria was advanced at IMO because according to the general opinion the criteria contained in the IS Code did not present a final solution. It was understood that such criteria should be based on probabilistic approach. Not much has been achieved in this direction, in spite of many contributions, because of difficulties that prohibited its advancement [1].

Recently, however, this idea came back to life again and the IMO SLF Sub-Committee included, in its work programme, development of such criteria under heading „performance oriented criteria". Obviously the criteria should be based on probabilistic approach and comply with the new philosophy of safety under which in 1997 IMO adopted guidelines for the application of Formal Safety Assessment (FSA) to the IMO rule making process [2].

FSA METHODOLOGY

According to the definition the FSA is *„a structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using cost-benefit assessment"*. FSA methodology should comprise the following steps (Fig.1) :

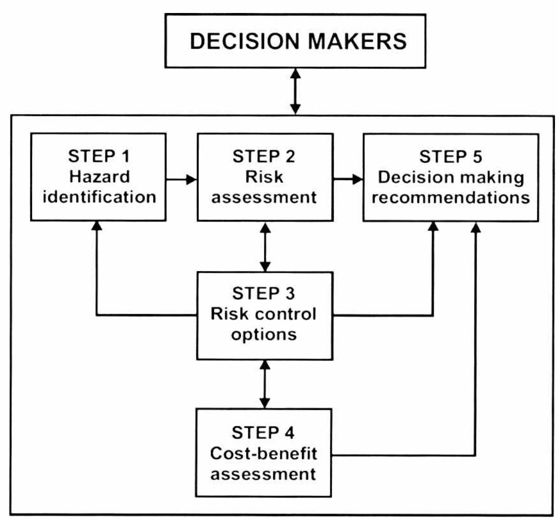

Fig.1. *Block diagram of FSA methodology*

Possibility of applying the FSA to safety against capsizing was discussed in several papers and it was also considered at meetings of the SLF working group on intact stability, however, apparently with no practical results, (e.g. [3,4]).

Since the adoption of the IMO recommendation on the FSA few attempts to apply this methodology to safety against capsizing have been known. Erickson et al [5] considered the case of shifting cargoes in holds. Alman et al [6] and McTaggart, de Kat [7] considered application of the FSA methodology, at least partially, to stability of naval ships in a seaway.

Application of the FSA methodology includes risk assessment. As risk is equal to probability of an accident times its consequences, the crucial element of this methodology would be calculation of the probability of ship capsizing in hazardous situations.

PROBABILISTIC APPROACH TO STABILITY AND PROBLEMS WITH ITS APPLICATION

The probabilistic approach appears obvious when considering performance-oriented stability criteria. There are serious arguments in favour of it. First of all the majority of factors affecting safety against capsizing, both external and internal, are of a random character. The external factors, such as wind and seaway are obviously random quantities. Less obvious is that the stability characteristics of a ship are also of a random character. For example, its displacement and the position of the centre of gravity vary randomly with the loading and unloading of cargo, fuel and stores consumption and with gradual changes of the mass of the ship with age. Variations of the metacentric height in service are also of a random character because of errors in the estimation of the position of the centre of gravity of the light ship during inclining experiments, and of errors in the estimation of mass and position of various pieces of cargo and stores. Those variations also introduce the element of randomness into the current estimation of stability.

The most attractive application of the probabilistic approach to safety against capsizing seems to be calculation of the probability of capsizing (or that of non-capsizing) during the whole lifetime of the ship (long-term probability of capsizing). This approach was for the first time proposed by the Soviet Union [8] and then discussed in several papers presented to various international conferences (e.g. [9]) but actually it was never included in the work programme of IMO.

The short-term probability of capsizing is calculated under the assumption that seaway, wind and stability characteristic of the ship are stationary. A proposal to use the short-term probability of capsizing as a criterion of stability was considered by IMO working group on intact stability in late seventies – early eighties. The general layout of the programme of work was proposed by Poland at 22nd session of the SLF [10]. The working group at its 29th session agreed in general to follow the proposed programme and it further agreed that the future criteria should be developed on the basis of probabilistic approach. The short-term probability of capsizing was suggested for a selected situations [11] and it was included in the long-term programme of the development of improved stability criteria.

Even if the long-term or short-term probability of capsizing were calculated with sufficient accuracy, then there would be some problems how to apply those probabilities as measures of safety and safety criteria. Those problems are discussed in the following.

LONG -TERM PROBABILITY OF CAPSIZING

During its lifetime, the ship may find itself in a number of different situations where each situation is characterized by ship's heading and speed, loading condition, sea state, wind force and direction, as well as other factors influencing stability.

If there are k such situations in which the ship may find itself during its lifetime, then the lifetime probability of capsizing can be expressed as :

$$LP_C = \sum_{k=1}^{K} P_{Ok} \cdot P_{Ck} \qquad (1)$$

where :

- K - total number of situations
- P_{Ok} - probability of occurrence of k-th situation
- P_{Ck} - probability of capsizing in k-th situation (i.e. short-term probability of capsizing in this situation)

It is assumed that in each of the K situations stationary conditions exist.

Practically, in order to calculate the long-term probability of capsizing it would be necessary to calculate the short-term probability of capsizing for a number of situations. The situations should be identified by taking into account geographical area, weather state, ship's heading relative to wind direction, loading condition and additional factors endangering stability, that may occur [12].

SHORT-TERM PROBABILITY OF CAPSIZING

The short-term probability of capsizing in a selected situation where stationary conditions exist may be calculated by the formula :

$$P_{Ck} = 1 - \exp(-\lambda \cdot t_k) \qquad (2)$$

where :

- λ - the so-called risk function (the probability of capsizing within the period (t, t + dt) on the condition that until then capsizing did not occur). λ value is assumed constant in every situation
- t_k - the time during which the ship remains in this situation.

PROBLEMS IN EVALUATION OF THE PROBABILITY OF CAPSIZING

Calculation of LP_C or even P_{Ck} meets serious difficulties. Calculation of the risk function λ in the formula (2), for short-term probability of capsizing could be in principle evaluated by applying three different methods:

* Analysis of records of casualties
* Model tests
* Mathematical modelling.

With regard to the first method it is unrealistic to assume that statistical analysis of casualty records may allow to calculate the risk function. There are very limited possibilities to perform a probabilistic analysis on the basis of available data.

Model tests provide extremely useful information on the behaviour of ships in a seaway, they also could be, in principle, used to evaluate the rate of capsizing in situations simulated in the towing tank or in open waters. Seakeeping tanks are equipped with wave generators usually capable to create waves of a desired significant wave height and wave spectrum. Model runs on the simulated irregular seaway, but because of limited length of the tank it usually meets only few waves. In order to take a long time record of motions and particularly to assess probability of capsizing the runs should be repeated many times, which makes such tests very time consuming and costly. Moreover, because each run starts from zero speed with randomly chosen realization of wave pattern, wave groups or extremely high waves may not be created. To produce a freak or abnormal wave is even much more difficult. There are known few successful attempts to produce such wave in a small model tank [13], however this is far from a standard practice in larger tanks where model tests may be actually performed. Realization of more complex scenarios, where other than environmental factors are taken into account, is hardly possible in towing tanks.

Model tests of capsizing could be also performed in open waters. Although such tests provide extremely useful information on the possible capsizing scenarios they appear very costly and time consuming because of necessity to wait for suitable weather conditions. This method was never considered as a standard practice.

MATHEMATICAL MODELLING OF CAPSIZING

Estimation of the short-term probability of capsizing on the basis of mathematical simulation of ship's motions in a seaway, is probably most realistic.

In normal design practice ship motions in waves are described by a set of linear differential equations and in order to estimate seakeeping characteristics a frequency domain analysis is performed.

For the sake of assessing survivability, because of large angles of heel, the mathematical simulation should be based on non-linear approach. Nonlinearities appear in representation of restoring forces (stability arms curve), damping forces and excitation forces due to non-linear waves. This makes the mathematical simulation extremely difficult and time domain approach is necessary. This in turn requires using very long 3D wave time series taken as realizations of certain wave spectrum. In principle the time domain simulation must be performed by taking a great number of waves, but even then, if the ship did not capsize it does not mean that it will not capsize if more waves are taken. Obviously, this kind of simulation does not include freak or unusual waves that are most dangerous. Simulations with taking into account such non-linear extreme waves were yet not attempted because they meet tremendous difficulties [14].

The results of simulations are extremely sensitive to initial conditions and they reveal several singularities, such as bifurcations, saddle points and also chaotic behaviour. It is very difficult to interpret the results in terms of probability of capsizing.

In majority of the mathematical models only environmental effects are considered, mainly waves, sometimes wind is also accounted for in a simplified way as additional factor. The other factors that may cause capsizing, besides some attempts to include the effect of water on deck [15,16], are not taken into account. To simulate more complex capsizing scenarios might be even more difficult.

The 23rd ITTC Specialist Committee on Prediction of Extreme Motions and Capsizing [17] reviewed at depth available mathematical models of capsizing and reached the conclusion that : *„only a few of these models consistently agree qualitatively with all the extreme motions and modes of capsize identified in free running model experiments. None of the models does so quantitatively."* Apparently much more effort must be made to achieve results applicable in practice, and in particular, mathematical models of capsizing scenarios that include several factors besides the effect of seaway, have to be developed.

LONG – OR SHORT-TERM PROBABILITY ?

Apparently, two options seem to be possible with respect of how probability of capsizing could be used as a safety-against-capsizing criterion: the short-term probability of capsizing and long-term probability of capsizing.

There are certainly some arguments in favor of the long-term probability because it takes into consideration all possible situations that the ship may meet during its lifetime. On the other hand the great majority of situations are not dangerous at all. This may result in „smoothing down" the final result. Another aspect is the way how the lifetime cycle of ship's operation is simulated. It might be easy if the ship is designed for operation on a definite route. The route could be then considered on the yearly basis, split into several sectors in which seaway conditions (season, sea state and direction) could be taken from the global wave statistics, loading conditions might be assessed from operational schedule [12] and the probability of meeting this situation could be estimated. It might be much more difficult if the ship was designed to operate around the world and the definite routes, times spend on each of them and loading conditions were not known.

Sevastyanov [18] pointed out the other problem of the application of the long-term probability. He argued, that the required accuracy of estimation of the probability of capsizing that is expressed by very small numbers lies outside the possibilities of the method.

The advantage of taking the short-term probability of capsizing as a criterion lies in the possibility to take into account many different scenarios relevant to particular types of ships and also the effect of rare events, which cannot be treated by classical theory of probability and cannot be confirmed by statistical data.

PROBLEM OF WAVE CLIMATES

The estimation of the critical seaway climates is crucial for the mathematical or physical modelling of capsizing in assumed situations. This fact was recognised by the IMO as early as in 1968, and at that time the Joint Ad Hoc Working Group for the Study of External Forces Affecting Ships was created with the task to study wave and wind characteristics. The Group at its five sessions considered characteristics of wind and waves, statistics of wave groups, sea spectra in various areas and attempted to assess wave characteristics at the time and place of some casualties by hindcast analysis [19].

When calculating lifetime probability of capsizing by using voyage simulation method, for each considered situation wave data could be taken from the Global Wave Statistics [20]. The Global Wave Statistics provides data on significant wave heights, modal period and direction of propagation for four seasons in various areas of the world's oceans, and there is a common practice to adopt in simulation attempts the seaway spectra (Bretschneider, JONSWAP) related to it. With the use of those data – wave scatter diagrams, short-term probability could be calculated by numerical simulation.

In the numerical simulations the seaway is most often assumed which consists of irregular 2D waves with the one-peak spectrum.

As a rule deep water is assumed. It would be also necessary to consider existence of wave groups in the deep-sea wave pattern that often cause capsizing. Moreover, in certain areas breaking and conical waves have to be considered that might be very dangerous especially for small vessels. Data acquired from the Global Wave Statistics are not good enough for assessing ship survivability in such situations. Ships with the unlimited range of operation must survive the extreme weather conditions that might be met during their lifetime.

For the purpose of assessing ship's survivability Buckley [21,22] derived worldwide climatic and extreme wave spectra based on millions of measurements taken primarily by NOAA buoys or taken from other sources. On the basis of the measurements envelopes of the modal period T_P versus significant wave H_S were drawn (Fig.2).

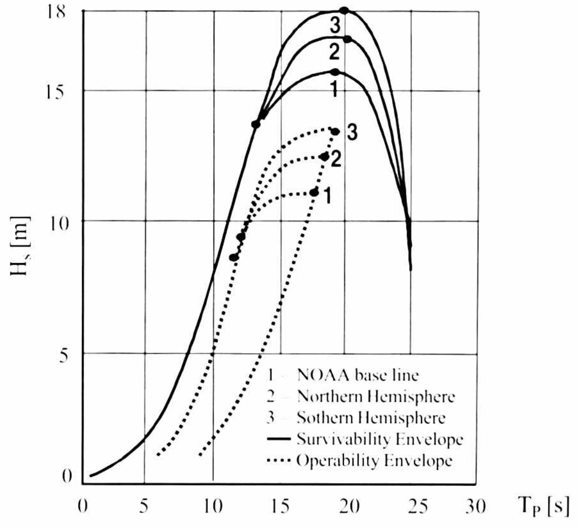

***Fig.2.** Survivability and operability envelopes [22]*

The survivability envelope shown in this figure corresponds to severe storm climatic conditions and it is recommended to be used in safety analysis, the lower one is the operational envelope used for evaluation of the design seakeeping characteristics.

It has to be noted that extreme wave heights are much larger than the significant heights. For example, by taking, from the survivability envelope, the wave of H_S = 14.0 m with corresponding T_P = 13.3 s and by using Longuet-Higgings formula the extreme wave heights presented in Tab. 1 are obtained [23].

Interpretation of those results shows that during the 36-hour typhoon the ship will meet waves of 30.0 m height with 63% probability and waves of 36.7 m height with 1% probability i.e. about 10 times in 36 hours.

Tab.1. Probability of appearance of extreme wave heights

P_{ex} [%]	63	10	5	2.5	1
H_{ex} [m]	30.0	33.5	34.5	35.5	36.7

The waves of extreme heights, freak or abnormal ones encountered from time to time have their characteristics entirely different from those of fully developed wind waves. They are highly non-symmetrical; their wave steepness H/λ might reach 10%, height above average water level up to 1.8 H_S and slope up to 30°. The wave profile recorded during the hurricane Camille is shown in Fig.3. [24]. Such waves are met apparently much more often as it could be anticipated on the basis of the linear wave theory.

The record shows a very steep and high wave that may cause ship to capsize or a large amount of water coming on the deck, resulting in serious damages and foundering of the ship. Presumably such a wave caused the foundering of the bulk carrier DARBYSHIRE. Some other records show that groups of very high and steep waves could be met during a severe storm.

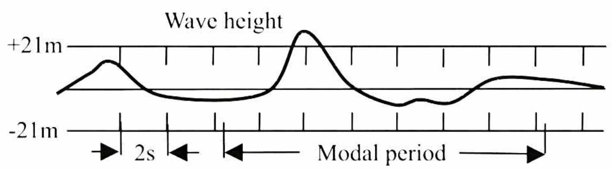

Fig.3. Wave recorded during the hurricane Camille [23]

PROBLEM OF IDENTIFICATION OF HAZARDS

When calculating the probability of capsizing in each considered situation, hazards that may cause capsizing have to be identified. This is also specified as the first step when applying the FSA methodology.

Obviously the most important hazards are from the side of the environment, but also other hazards must be identified and their probabilities evaluated. This could be accomplished on reviewing statistical data on casualties and on opinions of experienced seamen, especially those who survived casualties. Model experiments of capsizing in a seaway and mathematical simulation of capsizing phenomena could provide an additional important source of information.

The largest data bank on stability casualties was collected by IMO in the years 1963-85, where 166 loss-of-stability accidents were analyzed [25]. Also Aksyutin and Blyagoveschensky [26] described more than 200 loss-of-stability accidents. There are available some other statistics covering , however, much smaller number of casualties.

From those sources it may be concluded that besides environmental hazards there is a number of other factors that contribute to possible occurence of a loss-of-stability accident. Statistics and description of stability casualties shows that environmental effects are rarely a single cause of a loss-of-stability accident. It might be surprising that quite a large percentage of stability casualties occurred in calm sea. IMO statistics shows that about 27% of stability casualties occurred in moderate weather, 6% of which happened in still weather [25]. The other possible hazards are :

- shifting of cargo
- crowding of passengers on one side
- rudder action
- icing
- sharp turning
- opening not closed
- water trapped on deck
- fishing tackle.

The list is in no way comprehensive and some other hazards might be identified as relevant to special types of ships. Also human factor contributes quite often to the casualty, but this problem must be dealt with separately.

The most important and difficult problem is to decide which hazards have to be assumed as acting simultaneously. This could be assessed on the basis of experience supported by expert's opinions, and in this context the Delphic method is suggested. Important question is also to decide whether freak or abnormal waves have to be taken into account.

The existing prescriptive intact stability requirements include simultaneous action of some hazards, e.g. for passenger vessels, crowding of passengers, sharp turning and wind force but they do not take into account conclusions drawn from the statistics showing that in more than 40% of casualties shifting of cargo occurred also water on deck was present in 6% of casualties, and icing – in 11% [25,26].

PROBLEM OF CAPSIZING SCENARIOS

The simulation of ship's behavior and evaluation of probability of capsizing requires simulation of scenario leading to capsizing. Capsizing scenarios could be identified on the basis of the analysis of descriptions and statistics of casualties provided in the above-mentioned sources. There are, however, rare cases where the sequence of events is exactly known which may make identification of such scenarios difficult. The other source of information is the analysis of model tests of capsizing.

In early seventies IMO, considering possibility of development of „rational" or performance oriented stability criteria, agreed that such criteria have to be developed on the basis of calculation of the long term probability of capsizing. As this certainly was a formidable task, it was decided to specify the most dangerous situations that have to be taken into account for calculation of probability of capsizing. Several authors discussed at length the choice of such situations :

Cleary [27] Takaishi [28], Dorin et al [29], Kobyliński [9].

The problem of identification of capsizing scenarios that must be included in calculations of the short term probability of capsizing might be probably the most difficult one. This problem is considered in the author's paper to be presented to the STAB 2003 Conference [30]. Therefore capsizing scenarios are not discussed here and the readers are referred to this paper.

PROBLEM OF CHOICE OF CRITERIA

Selection of the probabilistic response criteria is another problem. When using the long-term probability of capsizing three criteria could be used in principle [31] :

1. Probability of safe operation during time t :

$$P_{NC} = \exp(-\lambda t) = \exp\left(-\frac{t}{T}\right) \tag{3}$$

2. Capsizing rate (risk function) :

$$\lambda = -\frac{\ln P_{NC}}{t} = \frac{1}{T} \tag{4}$$

3. Average lifetime of a ship :

$$T = \frac{1}{\lambda} = \frac{t}{\ln P_{NC}} \tag{5}$$

where :

P_{NC} - probability of non-capsizing.

The above criteria are strongly connected with each other. However the first criterion, the probability of safe operation during time t in the range which is of practical interest, is insensitive to large changes of the risk function and this actually makes its practical application very difficult.

The second criterion, the risk function averaged over the lifetime of the ship could be derived from the casualty statistics where a number of capsizings in relation to the total number of ships at risk is given. The rate of capsizings, N_C, could be assumed as related to the risk function λ and could be used as a criterion. At present, as it is seen from statistics, the hourly rate of capsizings of ships, at assumed 20-year lifetime, is of the order of $(0.4\text{-}0.6)\times10^{-6}$ which is a very small value. Using such a small value as a criterion requires great accuracy of its estimation, which would be very difficult to achieve because of the scarcity of statistical data.

The third criterion, the average lifetime of a ship before it capsizes, is not practical. From the formula (5) it can be observed that this will be of the order of 8000 years. It is clear that no ship has a chance to remain afloat during such a „theoretically possible" lifetime and any prolongation or shortening of this period will not have any effect on the opinion of mariners about its safety.

The short-term probability of capsizing may be better criterion of safety. Some trial calculations reveal, however, that this probability is very sensitive to assumed conditions, therefore the crucial point would be the choice of a critical situation and possible capsize scenario. Anyway this problem requires further consideration and a number of trial calculations.

PROBLEM OF ACCEPTABLE LEVEL OF RISK

Even if the probability of capsizing, either long-term or short-term one in assumed seaway conditions were assessed with sufficient accuracy, there would be some problems with the possibility of accepting of the probability of capsizing as a standard. The basic problem is the estimation of the allowable level of probability of capsizing. This problem could be solved in the following ways [32] :

- by comparing the probability of capsizing calculated for the particular design with the probability of capsizing calculated with the same method for a sample of existing ships (method of disclosed preferences)
- by investigating preferences of the public directly (method of expressed preferences)
- by risk-benefits assessment.

The first method was applied to develop some new safety requirements by IMO where the assumption was adopted that new requirements have to provide at least the same level of safety as the old ones. However, calculations of the short-term probability of capsizing for a number of the existing ships just meeting IMO criteria, by using the same method in each case, revealed that the probabilities differed sometimes by three orders [33]. Such a large scatter of probabilities may prevent this method from using.

The second method might lead to absurd results. The public behaviour is often irrational. Probably the most serious problems in accepting the probabilistic concept of safety result from the human nature. The realisation, for example, that safety is never absolute in the quantitative sense seems to disturb or even terrorise some people when the decisions on new enterprises have to be taken. From the other hand the public is not willing to resign from benefits that are related to a higher risk.

The third method is most rational and is, in fact, recommended within the FSA methodology. This is mainly economic but not technical problem hence it is not discussed here.

The guidelines for application of the FSA recommend for this purpose to apply ALARP (As Low As Reasonable and Practicable) principle that is illustrated in Fig.4.

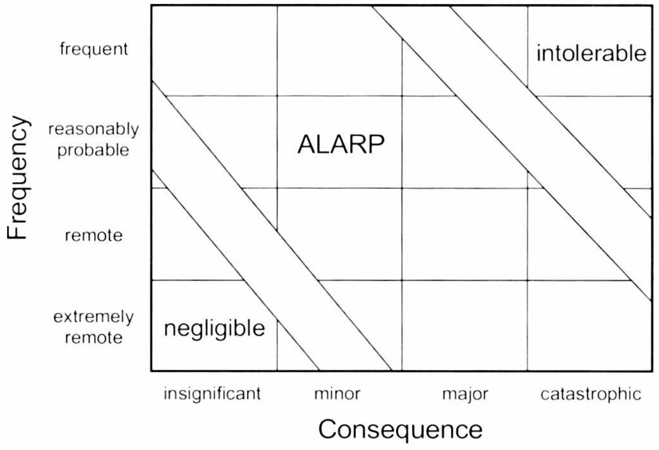

Fig.4. ALARP principle

CONCLUSIONS

From the above consideration of the problems that may be encountered in development of performance-oriented intact stability criteria for ships on the basis of probabilistic approach it is seen that this might be not an easy task. The IMO SLF Sub-Committee allocated only five years for completion of this task. But even if the problem of development of suitable and accurate enough methods of calculation of the probability of capsizing were solved during that time, which is doubtful, solving the remaining problems would require much more time. Therefore, according to the authors opinion, the time allocated for the development of such criteria must be much longer, and even if extensive research programmes were undertaken, it would take not less than ten years and probably even more.

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

Acronyms

ALARP	- As Low as Reasonable and Practicable
FSA	- Formal Safety Assessment
IMO	- International Maritime Organisation
IS	- Intact Stability Code
ITTC	- International Towing Tank Conference
JONSWAP	- Joint North Sea Wave Project
MSC	- Marine Safety Committee
NOAA	- National Oceanic and Atmospheric Administration
RINA	- Royal Institution of Naval Architects
SA	- Safety Assessment
SLF Sub-Committee	- Sub-Committee on Stability, Load Lines and Fishing Vessels Safety
SNAME	- Society of Naval Architects and Marine Engineers
STAB Conference	- Stability of Ships and Ocean Vehicles International Conference
2D, 3D	- two and three - dimensional, respectively

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Conference

Beginning of the next tenure of activity

On 3 April this year the Regional Group of the Section on Exploitation Foundations, Machine Building Committee, Polish Academy of Sciences, held its scientific-organizational meeting at the Faculty of Ocean Engineering and Ship Technology, Gdańsk University of Technology. Prof. Jerzy Girtler, Chairman of the Group, chaired the meeting.

During its organizational part a program and forms of activity for the current tenure of the Group were discussed. The scientific part was devoted to presentation of and discussion on two following papers :

- *Novel solutions of ship power plants for ro-ro ships* by Jerzy Cegła (Wärtsilä – Polska)
- *Science of safety* – by Alferd Brandowski (Gdańsk University of Technology).

At the end of the meeting to its participants an opportunity of being acquainted with the Laboratory of Fuel and Lubricating Oils, Ship Power Plant Department, was given.

Conference

TI

Information technologies 2003

On 18÷21 May 2003 the Faculty of Electronics, Telecommunications and Informatics, Technical University of Gdańsk, organized 1st domestic conference devoted to information quality covering the methods of information retrieval and processing, and methods of its transmission and interpretation.

About 120 participants had the opportunity of being acquainted with 81 papers which were read and discussed during nine successive topical sessions :

⇒ Visualization
⇒ Digital libraries
⇒ Information techniques in medicine
⇒ Communication services and protocols
⇒ Veracity of information systems
⇒ Information technologies and problems of education
⇒ Graph modelling of systems
⇒ Informatics in management and social sciences
⇒ IST international programs.

During plenary sessions the following papers were presented :

- *Problems of expert decision-aiding systems of incomplete representation of knowledge* – by Zdzisław Bubnicki (Wrocław University of Technology)
- *Resource management in GRID systems* – by Jan Węglarz (Poznań University of Technology)
- *Standardization of telecommunication equipment architectures* – by Leszek Pankiewicz (Intel Poland).

According to opinions expressed by the participants, the 1st domestic conference properly fulfiled its role as a forum for exchange of experience among representatives of the different centres dealing with contemporary information technologies. Therefore, it should be the beginning for successive special meetings of the kind in order to tighten cooperation for solving important inter-disciplinary problems in the area of information in the today „society of knowledge".

Despite the domestic character of the Conference, some invited guests from Belgium, Switzerland, and USA took part in it.