TRANSNAV
http://www.transnav.eu
the International Journal on Marine Navigation and Safety of Sea Transportation
Volume 8
Number 3
September 2014

DOI: 10.12716/1001.08.03.04

Challenges to ship hydrodynamics in the XXI century

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ABSTRACT: The beginning of twenty-first century is characterized with important changes in world shipping and exploitation of ocean resources. Three important trends are clearly visible: environment protection, safety and economy. They materialize in important changes in the structure of world fleet where some existing ship types are going to disappear and new ship types emerge. Increasing the size of some ship types is another visible tendency. Stress on environment protection has serious impact on the hydrodynamic characteristics of ships whether with regard to safety zero accident rate is the goal. Important challenges to ship hydrodynamics caused by those tendencies are discussed in the paper.

1 INTRODUCTION.

Ship hydromechanics and in particular ship hydrodynamics constitutes the foundation of naval architecture, the science of how to build safe and efficient ships. It is the most important branch of knowledge needed to design and construct ships and object of the off-shore industry.

Laws of ship hydromechanics are creating the basis for development of computer codes used recently for the design purposes of ship hull, propeller and appendages and for estimation of hydrostatic data and for resistance, propulsion, stability and manoeuvrability characteristics of the ship to be constructed.

In old times ships were built without any calculations and laws of hydromechanics were not known, although in some way they were intuitively respected, otherwise ships could not sail. Ships were built on the basis of experience that in turn, was based on trial and error method. Naval architecture was more art than science. With the development of in industrial world naval architecture gradually started to respect basic laws of hydrostatics and, later on, also hydrodynamics. By the end of the nineteenth century owing to the work of William Froude naval architecture started to be based on model experiments. During the second half of the twentieth century there was remarkable rapid development of theoretical and experimental ship hydrodynamics and with the advent of computer technology practical applications of sophisticated methods of ship hydrodynamics are possible.

Nowadays ship designers understand well that in order to design good ship they must utilize laws of ship hydromechanics.

2 WORLD FLEET AND OFF-SHORE INDUSTRY IN THE XXI CENTURY

In the beginning the twenty first century we may notice remarkable changes in ship types, in ways of transporting goods by sea and in methods of exploitation of sea resources.

This is obviously the result of global warming, and changes in the world climatic conditions, of developing economy, globalization of the world, increase of world population, wide exploitation of ocean resources. Also some poorly developed countries started to develop rapidly at astonishing speed.

The negative effect of expanding civilisation on the environment is well known. International community is worried that further industrial development may irreversibly destroy our present world. People realized that in order to prohibit further devastation of sea environment ships must be constructed in such a way, that strict environment pollution limits must be imposed on shipping. This resulted in proposing EEDI (Energy Efficiency Design Index) values that, if finally made a law, will considerably influence the construction of future ships and off-shore facilities. This resulted in the concept of "green ships", i.e. ships with extremely low emission of noxious and toxic gases and wastes, that make no harm to the environment. Green ships must characterize also by low fuel consumption, because low fuel consumption means not only economic gain, but also smaller emission of harmful substances.

The way of transporting goods by sea became now entirely different because of containerisation. This resulted in appearing new ship type, container ship. When about 50 years ago first small container ships were constructed, currently the size of container ships increased enormously, as fig. 1 shows, the largest container vessel reaching 18 000 TEU and length about 400 m. Currently majority of general cargo is transported in containers and old general cargo ships almost disappeared.

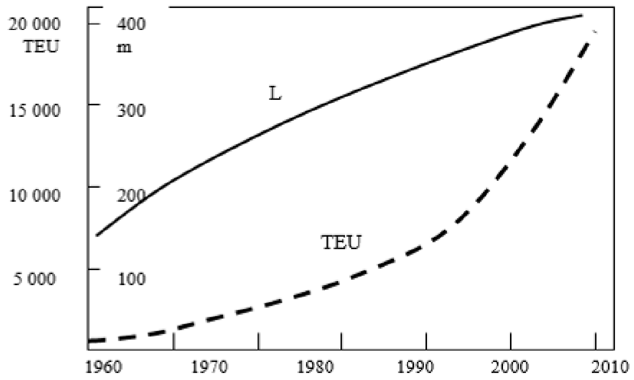

Figure 1. Development of size of container ships.

During last twenty years bunker prices increased considerably. This tendency will last and looking ahead to the year 2025 bunker prices are likely increase by 50%. In order to cut the operating cost and at the same time to reduce the pollution, most container companies adopted the slow steaming policy, reducing the speed of their container ships to 17 or even 14 knots. This also may be a remedy for existing overcapacity in particular in containers fleet.

Another remarkable change in shipping is development of cruise passenger ships. Old passenger ships almost disappeared and passenger transport was overtaken by airplanes. But passenger ships were replaced by cruise ships which carry passengers in luxury conditions. In those ships, according to definition, passengers are boarding in the same port as disembarking. The size of cruise ships from the time that first cruise ships emerged is doubling in every decade as Table 1 shows, and finally modern cruise vessels are real monsters reaching length of almost 380m and carrying more than 6000 holidaymakers.

Table 1. Development of cruise vessels

Year	Name	Number of cabins	Length [m]
2010	Allure of the Seas	2712	360
2006	Freedom of the Seas	1816	339
1999	Voyager of the Seas	1565	311
1996	Grandeur of the Seas	975	279
1990	Fantasy	1028	260
1982	Song of America	707	214
1970	Song of Norway	377	168

Rapidly expanding off-shore industry is another remarkable development of the recent times. It caused that several new types of ships emerged, many of them designed to perform tasks that were never before heard.

In particular, in off-shore industry, apart from traditional drilling platforms, many types of service ships as well as ships for specific tasks emerged. Acquiring "green energy" from wind and some opposition to the installation of wind farms on land caused fast development of wind farms on coastal sea areas. This led to the development of special type of ships for installation of wind towers in shallow waters and also special type of ships for servicing wind towers. Example of such ship for installation of wind towers in wind farms, is shown in fig. 2.

Figure 2. Wind farm installation ship [1]

In near future because of global warming and consequential reduction of ice covered waters, arctic waters will become navigable and also accessible for exploitation of gas and oil resources. Attention of several countries is therefore focused on ship types and oil rigs that may be used in these regions. An example of oil tanker specially designed for operation in arctic waters is shown in fig. 3. Attention is drawn to the propulsion system consisting of two azipods of conventional type with mechanical gear however. Such propulsion system never would be used in conventional tankers.

Apparently azipods reveal certain advantages for ships sailing in ice covered waters because high power azipods with mechanical gear have been recently developed and advertised.

Figure 3. Tanker designed for arctic waters. [2]

Another remarkable tendency in shipping in the XXI century is the tendency to increase safety standards, in particular safety standards for passenger ships, either cruise ships or others, e.g. passenger car ferries. Important casualties, if only to mention Estonia or Costa Concordia disasters, stirred public opinion and forced authorities and the International Maritime Organisation (IMO) to include in their work programmes development of enhanced safety standards for passenger ships.

The importance of safety at sea and protection of sea environment from pollution from ships is now well recognized and IMO is actually responsible for development and for implementation of respective requirements in the form of regulations and recommendations. For the first time in history of seafaring international organization responsible for safety at sea and protection of sea environment was created. IMO work influences greatly the design of future ships and this in turn, creates new challenges to the important element of design, ship hydrodynamics.

All these factors caused that naval architecture and in particular ship hydrodynamics faces some important challenges. There are at least three important areas where this is particularly felt: environment pollution, safety and economy.

3 SHORT HISTORICAL DEVELOPMENT OF SHIP HYDROMECHANICS

Ship is floating object. It is therefore subjected to laws of hydromechanics. If the ship is at rest in calm water, Archimedes law is valid. The static pressures act on the submerged external surface of ship hull. This is comparative simple problem of hydromechanics, well known since Archimedes times, in fact it consists of calculation of areas and volumes. Ships were built for centuries with only some hydrostatic calculations made.

In old times this was only Archimedes law that was intuitively observed and because of that before Archimedes, people did not realize that when building ships they obeyed Archimedes law, but intuitively they made use of it.

With progressing time and development of technology ship hydromechanics was studied, and shipbuilders made more and more extensive use of it. At first only hydrostatics was studied, floatation, static stability, subdivision. Later on, ship hydrodynamics was applied in ship design, firstly ship resistance and propulsion, later on ship motions in waves, manoeuvrability, dynamic stability and theory of propellers. Nowadays, with the advent of computerised design ship hydrodynamics constitutes background of any computer code used in ship design process.

Basic laws of ship hydrodynamics were known quite a long time ago. Leonhard Euler and other scientists made important contribution in this respect, but naval architecture was really more craft than science. Only in the second half of the nineteenth century hydrodynamics began to influence naval architecture appreciably. Bouguer, however, laid down the fundamentals of naval architecture based on hydrodynamics little earlier. Still, even in the twentieth century, before the second world war, only laws of hydrostatics were applied, ship hydrodynamics played small part in naval architecture and its application was limited to the extensive use of some empirical formulae. Only after the second world war we may observe development of calculation methods based on accurate theoretical background.

Emerging computer technology enabled transformation of theoretical models into practical calculation methods that are used in ship design process. In the advent of twenty first century we observe rapid development of computer technology, we observe also new challenges to shipbuilding. This in turn developed new challenges to ship hydromechanics. Although basic theory remains the same, new tools available make possible to develop practical methods used in ship design process based on rigorous theoretical approach that was never possible in the past.

In the nineteenth century when mechanical powering replaced sails and oars the need arose to predict accurately the necessary power of engines in order to achieve desired speed. This was problem of estimating forces acting on moving ship and problem of efficiency of screw propulsion. With lack of possibility to made prediction on the basis of theoretical calculations, model tests were proposed by William Froude and his method is used until these days. Model tests found wide application not only with regard to propulsion, but later on, also to other ship characteristics, as for example motion amongst the waves and manoeuvrability.

Theoretical equations enabling calculation of forces acting on the moving ship and prediction its motions were known, but practical calculations were not possible due to extremely large amount of work needed. Wide application of computer technology at the end of the twentieth century made it possible to find methods based on Navier-Stokes equations applicable to make accurate analysis of flow pattern around of the body of the moving ship, and to calculate forces acting, but model tests remained still the most reliable method of simulating the highly complicated phenomena of flow around ship hull and propeller, in particular when the ship is moving amongst the waves.

Computer programmes are now widely used for analysis of flow and for optimisation purposes and now they consist important part of any design procedures of modern ship, where the model tests still remain important tool in the design process. This situation may change, however. Bearing in mind that the computer capacity is doubling in every three to four years one my hope that in the future the capacity of available computers will be sufficiently large for tackling the most sophisticated problems of ship hydrodynamics. It does not mean, however, that model tests will be totally abandoned, but they may be limited to testing final designs or to testing entirely new solutions.

4 NEW CHALLENGES TO SHIP HYDROMECHANICS

As it often happens, prediction of the future development of technology very often appears to be wrong and reality happens to be quite different from the forecast. However, looking carefully at the world political and economic development after the second world war and in particular at the development of sensitivity of the society to world warming, air and sea pollution and safety at sea it is not too difficult to predict important challenges to basic sciences and in particular to ship hydromechanics at least for foreseeable future.

It seems that three factors will govern future challenges in this respect: air and sea pollution and the concept of "green ships", economic considerations and reduction of cost of transport and general tendency to enhance safety at sea, in particular safety of passengers. There is also, however, the tendency to increase exploitation of sea resources, in particular in arctic waters and to develop transport routes in arctic waters, because due to global warming they may be accessible in near future.

4.1 *Green ship concept and impact of economy*

Green ship means a ship with low emission of noxious gases and wastes but on the other hand economically viable. This means low consumption of fuel, fuel with low content of poisonous substances, e.g. sulphur, waste recovery installation. EEDI values should be respected. From the ship hydrodynamic point of view this actually means reduced propulsion power as a result of smaller resistance and higher propulsion efficiency. This is important challenge related to environment protection and also to economic considerations.

Resistance is function of speed and it varies depending of ship form. Propulsion efficiency depends on propeller efficiency and wake field in place where propeller works. Both depend also from ship operation, loading conditions, manoeuvres performed and some other factors.

The largest gain in overall propulsion efficiency may be achieved by reduction of speed. Choice of speed is a matter of economic calculations. The higher speed the higher turnover of goods, but on the other hand the higher cost of transport. With rising fuel costs rising speed influences the overall cost of transport negatively. In late twentieth century there was tendency to increase the speed of transporting goods and ships were designed for higher speed. Currently it was discovered that lower speed may reduce overall cost of turnover goods, therefore ships not necessarily must be built for high speed. Lower speed means lower power needed to propel the ship, therefore at lower speed it would be easier to meet new international regulations related to lower emission of noxious gases and wastes.

Optimisation of ship form, propeller efficiency and overall propulsion efficiency during the design stage of slow steaming conventional ships usually resulted in about 4-6% power saving, but in certain cases gain may be as high as 15%. This is achieved by using CFD computer programs for analysing flow and extensive model tests. Development of accurate simulation models of the propulsion system consisting of propeller, ship hull and appendages is important challenge to ship hydrodynamics.

It is well known that the lower loading of the propeller (therefore increased diameter) will increase propeller efficiency. The problem is, how to accommodate large diameter propeller at stern and find the place where the propeller should be located in order to utilise in the best way mutual interaction of the propeller and the wake field. Several proposals are now advanced that must be investigated, one of them is show in fig. 4 where the propeller is shifted far towards the stern where it may be located in the crest of stern wave and the propeller itself is of large diameter extending lower than the base line. Overall propulsion efficiency may be increased even by 15%, as fig. 5 shows, but manoeuvrability of the ship may be considerably impaired. Therefore proper rudder arrangement must be developed or some additional movable fins installed. Anyway this is new problem or ship hydrodynamics to be solved. This arrangement basically is proposed for tankers and bulk carriers.

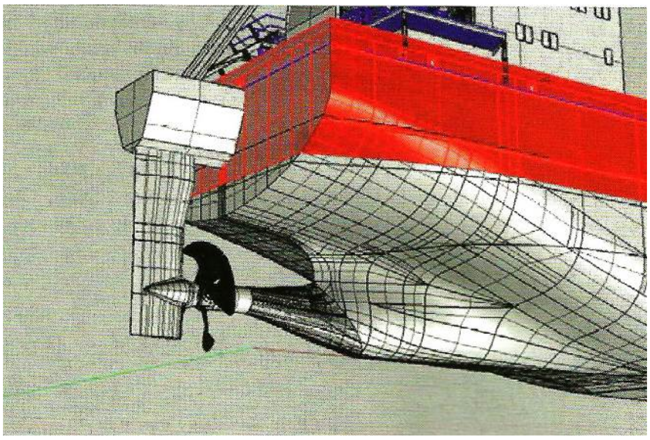
Figure 4. Illustration of the large area propeller concept. [3]

With the slower ships other ways of reducing resistance and propulsion power came to the attention of naval architects. Method of air lubrication of the wetted surface of the hull, idea that is known for a long time but was never practically applied, is considered anew with some prospects of success. This will, however, require further extensive research.

Twin screw propulsion, where wake field is modified by suitable arrangement of fins and vanes and propellers designed to be adjusted to the modified wake field is another trend that has to be investigated. If applied to large container vessels this solution may provide overall gain in propulsion efficiency up to 12%. Apart from economic gain the result of increased propulsion efficiency is reduction of emission of toxic and noxious gases. With the high cost of fuel as it is now the economic effect is particularly important (fig. 6).

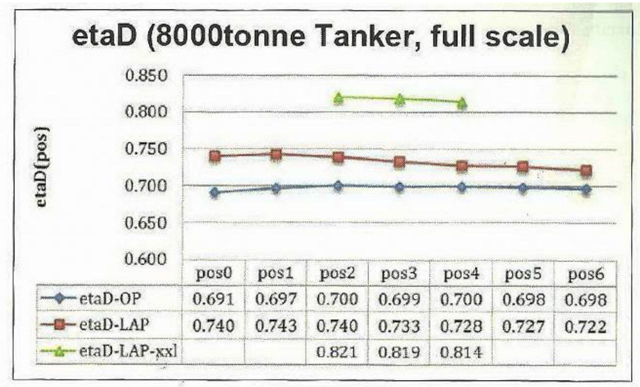

Figure 5. Effect of position of the propeller and propeller diameter on propulsive efficiency. The upper line shows the effect of large diameter propeller. [3]

For tankers and bulk carriers some innovative arrangements of propulsion systems are now considered and have to be investigated. Twin screw propulsion with highly efficient azipods or azimuting nozzles is considered as possible solution. (see fig 3). This installation may improve manoeuvrability considerably, but the effect on propulsion efficiency is dubious and it has to be investigated. In all cases fighting for higher propulsion efficiency will be attempted because this may help to achieve EEDI limits. Method for efficient control of the velocity field constitutes important challenge for ship hydrodynamics

Installation of rigid sails on slow steaming ships is another possibility. This was actually considered several years ago and then abandoned, but now this possibility is going to be reconsidered because it appears that it may be realistic.

Figure 6. Arrangement of shrouded propellers and vanes. [4]

All these proposals constitute important challenges to ship hydrodynamics and some international research programmes aimed at development of new solutions of propulsion arrangement of ships are already installed. Apart of this, some large shipping companies installed their own highly financed programmes with some positive results achieved already. As an example Maersk and Rolls Royce may be quoted. Several programmes were installed also in China, the country where about 50 per cent of all sips are recently under construction.

4.2 *Safety*

High stress is now put on safety of navigation. In particular safety of passenger ships, either cruise vessels or ropax ferries is considered inadequate. Estonia disaster and recent Costa Concordia disaster did show that even ultra large passenger ships may be endangered. Fortunately in Costa Concordia casualty there were few fatalities, but that was only because of the lucky situation that the ship was drifted to the rock and not capsized or foundered.

Zero accident rate in passenger ships is the goal of the new IMO approach to intact an damage stability of passenger ships. Ships must not only withstand adverse weather situations but even in damage condition it is essential that they must reach safely nearest port of refuge or being towed to that port. If that is impossible they must survive sufficiently long time in order that all passengers and crew could be safely evacuated. Costa Concordia accident did show that evacuation was possible only because the ship was securely sitting on the rock, otherwise the number of fatalities would possibly be extremely high.

As the size of cruise ships is increasing rapidly and voyages are now arranged even in remote parts of the world where distance to the nearest port of refuge may be as large as thousands miles, achievement of this goal in not an easy task. Damaged ship may be exposed to harsh environmental conditions and must withstand those situation. Behaviour of the damaged ship in waves and under severe wind condition poses serious challenge to ship hydrodynamics. IMO discusses this problem for some time, but end result is not yet predictable. There is of course simple solution, putting many more bulkheads, but this is strongly opposed by ships operators claiming that such ships will be practically impossible to operate economically.

Intact stability requirements of all ships are currently under review and so called second generation stability criteria are under development. Those criteria are intended to take into consideration those hazards, that are not taken into account in the present criteria. However, development of those criteria appears to be not an easy task and apparently they might be in force many years from now if at all.

It is possible that general approach to intact and damage stability issues may be changed entirely. Instead of prescriptive safety rules risk analysis and goal oriented requirements will be implemented as it is now discussed [5]. Actually risk assessment approach has been already applied to safety problems in some areas, e.g. in fire protection chapter of SOLAS convention. This is encouraged by the Marine Safety Committee of IMO and currently international research programmes were installed with this ultimate aim. As the author discussed this problem in another paper presented to this conference, therefore he refrains from discussing it further at this place.

4.3 *Off-shore and arctic waters activity*

Off-shore industry is fast developing industry that started in the second half of the twentieth century with exploitation of oil wells located at comparatively small water depths, but later on expanding rapidly all over the world. Now, apart of traditional drilling rigs and production platforms located in large oil fields at different depths of water, sometimes as deep as 600 metres, in smaller oil fields only singular oil wells are installed without connecting pipelines and oil is transported using shuttle tankers. Shuttle tanker is a specially constructed highly manoeuvrable tanker taking oil from the oil rig or FPSO (Floating Production, Storage and Offloading Unit). Shuttle tankers are fitted usually with sophisticated system of propulsion devices consisting of azimuthing propellers and thrusters assuring high manoeuvrability required when approaching take off tanker or drilling rig or FPSO. Design and operation of such ship poses considerable challenge to ship hydrodynamics bearing the fact that different propulsion units may be employed, some of them of novel type. Optimal construction and mutual interaction of several propulsion units have to be investigated and their characteristics estimated. Automatic systems of operation of multiple propulsion units, so called dynamic positioning systems, usually is essential.

As in near future exploitation of oil fields in arctic waters is planned where special types of vessels, *inter alia,* shuttle tankers will be employed, special environmental conditions in those areas must be taken into account. Research programmes in this area have been already installed and this is another challenge to ship hydrodynamics.

Another type of ships where similar problems emerged are OSV (Offshore Service Vessels) and ships servicing wind farms. Wind farms are new development and in near future thousands of wind towers may be installed in different parts of the world. Special type of ship for installation of wind towers was developed that in similar way as MODU (Mobile Offshore Drilling Unit) could be put on legs on the bottom has been developed (see fig. 2), but for servicing wind towers small service ships similar to OSS have to be employed.

In order to achieve good manoeuvring and propulsion characteristic of all these ships different propulsion devices such as shrouded azimuthing propellers with mechanical gear, Voith-Schneider propellers, valvistaar pods with vertical or horizontal axis and others are supposed to be installed. All of them require thorough theoretical and experimental investigation, optimisation of their characteristics and development of design procedures and that is another challenge to ship hydrodynamics.

5 CONCLUSIONS

As it is seen from the above review there are many new important challenges to ship hydrodynamics in the twenty first century. The whole development of sea transport and exploitation of sea resources will depend on the meeting those challenges and in order to do so, several, preferably international, research programmes have to be installed, possibly involving scientific institutes and universities from one side and industry and shipping companies from the other side. On the other hand in order to execute such programs there is urgent need to train highly qualified research staff and this is the main task of universities and their shipbuilding departments.

Poland has fifty years tradition of contributing effectively to the ship hydrodynamics and a number of scientist of polish origin were active in this field in several countries.

Regretfully in Poland, country that was formerly a leading country in shipbuilding, the profession of ship hydrodynamics almost disappeared. In Polish universities chairs for ship hydrodynamics disappeared and specialists in this field are not trained practically any more.

If this situation it will continue, then in Poland there will be no possibility to design ship hull and its propulsion effectively and also no research project could be performed because of lack of specialists able to do so.

In the opinion of the author there is currently an urgent need to re-install chair of ship hydrodynamics (or theory of ships), preferably at the Gdansk Technical University, that practically is the only place where shipbuilding and off-shore technology remains the subject of teaching and the place where new cadres of scientists may be educated.

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