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Writer: Nadiya Bukhanevych	Bukhanevych (Writer's signature)
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A very special thanks needs to be given to my sister, Anna Frantzen, and to my family members for their support in every way possible. My sincere thanks also goes to all my friends for "being my friends".

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Stavanger, UiS

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Nadiya Bukhanevych

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ABSTRACT

With the development of the Norwegian and the Barents seas and by advancing the oil and gas industry further to the sea from the coastal line, the marine industry requires a class of different purpose vessels to operate them at a pretty large distance from the shore line. These vessels should also be capable of working in the conditions of the specific and harsh weather in the Norwegian and the Barents seas.

This report describes the opportunities and abilities of multihull vessels by using examples of catamarans and trimarans. Examples of calculations of some methods and practical analysis of the opportunities will be the results here.

In this report the opportunities and advantages of trimarans and catamarans will be compared. Where trimarans, by keeping all advantages of catamaran design (the larger deck area and cross-section stability), have a higher speed and are less addicted to the impact from longitudinal rolling and they are more stable on a water surface..

Multihulls are having a certain number of disadvantages, for example, water impacts (during roll) to the area, where the beam connects to the hull (it is more expressed for catamarans, because of the double hull structure and hulls connect to each other by a cross-section beam), the weight of the hull increases, because of the double or triple hulls, and there are difficulties during construction and repair.

In this report "The elasto-dynamical theory of multihulls in nonlinear beam sea" will be considered. Also will the features of the water's resistance to the motions of multihulls be studied. These are defined by the arrangement and geometry of the underwater part of the hull and will be shown. By the calculation of:

- *the resistance of catamarans with a cruiser stern*
- *the resistance of a trimaran*
- *the resistance of a high-speed catamaran.*

Furthermore, the most suitable propellers will be reviewed; and also some calculations of the interaction coefficient of the screw propeller and the catamaran's hulls and calculation of the propulsive quality of a catamaran in a still water will be carried out.

This Thesis report describes the features and the opportunities of construction of the given types of the vessels at shipbuilding plants of Ukraine. Examples and data of the largest shipbuilding yards of Ukraine will be included. This report also focuses on specifications and considerations of oceanographic and geographic features of the Straits of Bosporus and Dardanelles for the opportunities of transportation from the Black Sea to the Mediterranean Sea through these Straits.

ABSTRACT IN RUSSIAN / ВВЕДЕНИЕ

С развитием освоения Норвежского и Баренцевого морей и продвижением нефте-газовой индустрии всё дальше и дальше от береговой линии морская индустрия более остро нуждается в классе специализированных судов разного назначения для работы в отдалённых морских районах. А также в условиях специфической погоды,что присуще Норвежскому и Баренцевому морям.

В данной Дипломной работе будут рассмотрены возможности и способности многокорпусных судов на примере катамаранов и тримаранов. Будут приведены не только методики, но и примеры расчётов по ним, что способствует практическому видению возможностей использования многокорпусных судов.

Эффективность применения катамаранов и тримаранов в тех случаях, когда нужны большая площадь палуб, остойчивость, вместимость, поворотливость, умеренная бортовая качка, скорость хода, надёжность главных механизмов, возможность текущего ремонта и обслуживания во время работы судна, подтверждена неоднократно практикой эксплуатации данного типа судов.

Будут рассмотрены возможности и преимущества трёх корпусных судов по сравнению с двух корпусными, которые сохраняя преимущества двух корпусных судов (большая площадь палубы и поперечная остойчивость), имеют лучшие ходовые качества и менее подвержены неблагоприятному воздействию продольной качки и являются более стабильными, как при ходе судна, так и при работе в море.

Многокорпусные суда имеют конечно и ряд недостатков,например,удары воды при продольной качке в область соединительного моста(это более выражено у катамаранов, из-за 2-х корпусного строения, соединённого поперечным "мостом"), увеличение массы металлического корпуса, трудности постройки и ремонта данного типа судов.

В данной работе будет рассмотрен "метод конечных элементов" или "упруго-динамическая теория" многокорпусных судов при нелинейных боковых волнах. Так же будут изучены особенности сопротивления воды движению многокорпусных судов, что определяется расположением и геометрией подводной части корпуса. На примере:

- *сопротивления катамаранов с крейсерской кормой*
- *сопротивления тримарана*
- *сопротивления глиссирующего катамарана.*

Будут предложены наиболее подходящие основные элементы гребного винта; а также будет проделан расчёт коэффициентов взаимодействия гребного винта и корпуса катамарана. Будет выполнен расчёт ходкости катамарана на тихой воде согласно заданным исходным данным .

Отдельной темой и главой будут рассмотрены возможности и особенности постройки данного типа судов на судостроительных заводах Украины и г.Николаева. Будут приведены примеры и данные крупнейших судостроительных заводов Украины. А также будут рассмотрены и специфицированы, как океанологические, так и географические особенности проливов Босфор и Дарданеллы для возможностей провода и прохода катамаранов или тримаранов через акватории этих Каналов и вывода данного типа судов из вод Чёрного моря в Средиземное.

CHAPTER 1: FUNDAMENTAL CONCEPT OF MULTIHULLS

Introduction to multihulls

A catamaran / trimaram is a multihulled boat (see Figure 1.1) consisting of two or three hulls respectively, joined by beams. The design and names for the multihulls components are derived from the Polynesians, who were built multihull sailboats almost 4000 years ago. While the English adventurer William Dampier was traveling around the world in the 1690s in search of business opportunities, he found a kind of vessel on the southeastern coast of India. He was the first to write in English about it. It was little more than a raft made of logs. *He wrote in 1697:*

"...they call them Catamarans. These are but one Log, or two, sometimes of a sort of light Wood so small, that they carry but one Man, whose legs and breech are always in the Water"....

Multihulls have been used as sport sailing boats, as fishing boats and in the middle of 20^{th} century they became more popular in the world marine industry. The multihull's large deck area and high stability make it an attractive for recreation and commercial craft.

Figure 1.1 Example of a trimaran and a catamaran.
(Ref. - http://images.google.no/images?hl=no&q=catamaran+/trimaran,pictures).

In sailing sport, multihulls in general, have been met by a degree of skepticism from Western sailors accustomed to more "traditional" monohull designs, mainly because multihulls were based on strange concepts, with balance based on geometry rather than weight distribution. However, the catamaran has arguably become the best design for fast ferries, because their speed, stability and large capacity are valuable.

Advantages and Disadvantages of multihulls.

Although it is possible for a catamaran and a trimaran to capsize, this is less frequent than with monohull boats because of the greater resistance to rolling. Most monohull designs are considered nearly unsinkable because even when filled with water, the flotation of one lateral hull is enough to keep the entire vessel afloat. Because of their stability and safety, special multihulls have become popular with sailors who have restricted mobility.

The greater speed compared to monohulls can also become important for safety when weather conditions are bad or threaten to deteriorate because the boat can leave the area of danger faster.
The waterline to width ratio is larger, allowing the thinner hulls to be driven through the water at higher speeds, as each works somewhat independently of the other(s).

Duplication of systems enables backups should failures occur. In a catamaran (the most popular multihull), most have twin engines and thus almost always a way of getting home. Many essential items are able to be duplicated e.g. water tanks and fuel tanks.

When it comes to disadvantages, multihulls capsizes are more likely to be of the pitch-pole type than a roll to one side due to their higher sideways stability and speeds. Capsized catamarans/trimarans are harder to turn upright than monohull boats (if the size of the boat is small). A capsized multihull should not be righted by sideways rotation as this usually causes heavy damage of the beam and rigging.
The width of a multihull vessel is often an issue, especially when docking. They are also more expensive to produce than a monohull of the same length.

The inherent inertia of a monohull dampens a great deal of oscillations and other surface effects. For example, monohulls can power through waves that a multihull would be forced to ride over. This means that multihulls are more prone towards hobby horsing especially when lightly loaded and of short overall length.

(Ref. - **http://en.wikipedia.org/wiki/Trimarans**)

(Ref. - **http://en.wikipedia.org/wiki/Catamaran**)

The main requirements (Performance, Safety, Handling, Comfort and Price) will give us a relevant information to understand and make a choice: "What geometry of the hull should be chosen for different purposes in the sea?" (Ref. - **http://www.multihull-maven.com/Seaworthiness**)

Performance

Faster - means extended cruising range and possibly less crew fatigue. Speedy boats can better avoid storms and avoid exposure to danger.

The cost of speed might be in the boat price, fuel costs, crew discomfort or increased risk of mishap. Most people will be interested in what it takes to get maximum performance in line with other wishes, like lots of deck space and maximum seaworthiness. Good performance should be obtained on any day and on any course too.

Stability

A vessel should survive all the waves and winds that the weather can throw at it. As far as possible, it should get directly from A to B. Any vessel must be stable through the whole range of conditions from good to frightening; that is, if any foreseeable combination of hydrodynamic, aerodynamic, or other forces disturbs its balance, the boat must have a strong enough tendency to return to even keel. This nautical 'virtue' is stability. Stability is a significant requirement for vessels (see Figure 1.2).

The power to remain upright (or stable) is called Static Stability. More static stability means safer speed-course in strong winds and gusts.

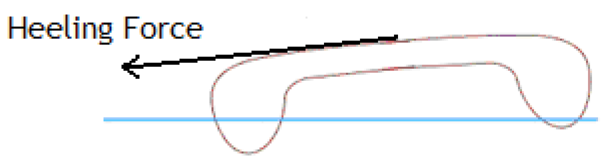


Figure 1.2. Heeling Force acting on a Catamaran.

(Ref. - **http://www.multihull-maven.com/Seaworthiness**)

The static stability is a very useful measure of how a vessel will behave and perform, but, as it ignores the important effects of the boat and the moving water, it only reveals part of a vessel's general seaworthiness. Getting a more complete picture of seaworthiness (which is a measure of a vessel's ability to provide safety and comfort in all weather conditions) also requires understanding a boat's Dynamic Stability.

Zero power to carry anything – static instability

Imagine a log (beam) floating down to a logging collection point. The log floats very well and will not sink, but if someone without exceptional skill and balance were to stand on it, the log would probably rapidly roll them into the water before they were able to take advantage of its buoyancy.

Although the log plus the person has ample buoyancy, the system is statically unstable. Any small roll of the log results in an out of balance force that causes even more roll (Fig.1.3).

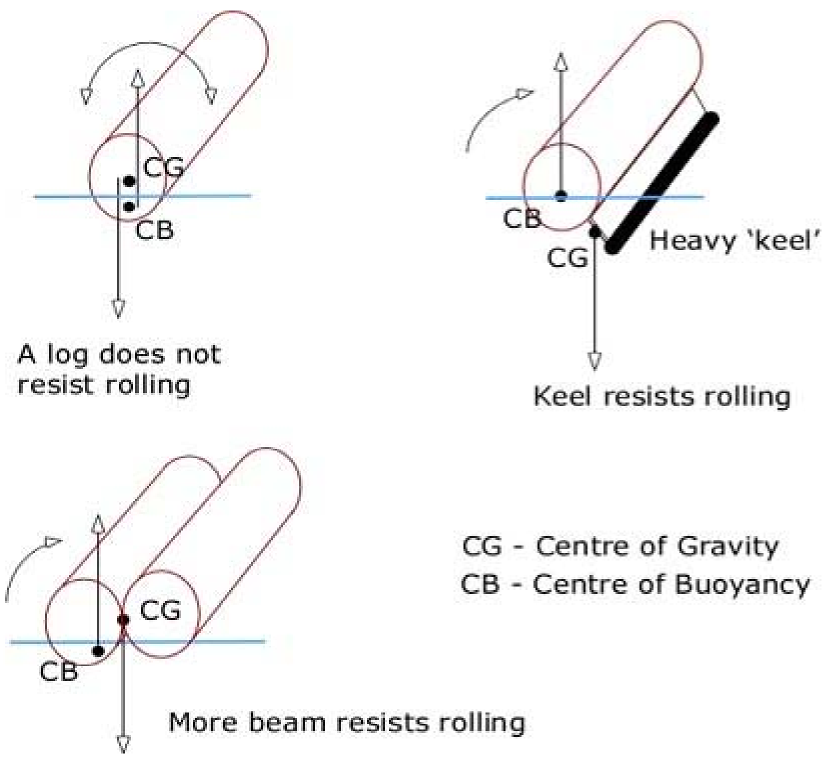


Figure 1.3. Roll of the structure. (Ref. - **http://www.multihull-maven.com/Seaworthiness**)

Increasing static stability by adding a keel

If we suspend a heavy weight on a plate deep beneath the log (see Figures 1.3 and 1.4), we will find that not only could we stand on the log but that it would carry cargo too.
When the 'boat' heels due to wind pressure or due to the person moving his or her weight, there is always a force restoring the craft to an even keel. Of course the extra weight will cause the log to float lower in the water – which is a disadvantage if we want to get our log to float fast.

Increasing static stability by increasing beam

There is another route to getting stability. This time forget the weight; we just lash two logs together (Figure 1.4). As long as the centre of buoyancy moves outside a vertical line from the centre of gravity we will benefit from a stabilising force.

Instead of lashing the two logs close together, this time we will tie them to a wide frame (Fig.1.4).

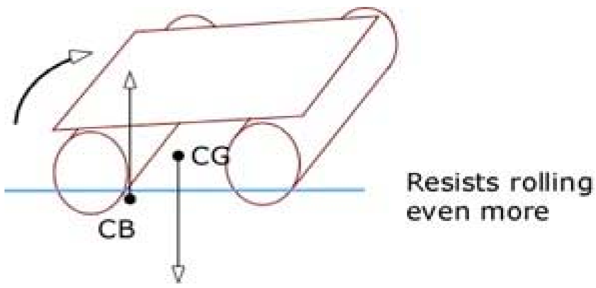


Figure 1.4. Increasing of static stability by increasing beam. (Ref. - **http://www.multihull-maven.com/Seaworthiness**)

Static stability of multihulls

When a 'catamaran' heels, the centre of buoyancy rapidly moves dramatically towards the extremity of the craft (see Figure 1.5). This seemingly gives us unlimited stability as long as we are able to keep increasing the separation of the hulls. Of course, as in the case of the monohull, there are practical limits if we are to maintain good seaworthiness. However, with the multihull, we have a lot more potential to exploit stability due to buoyancy alone and still maintain excellent seaworthiness.

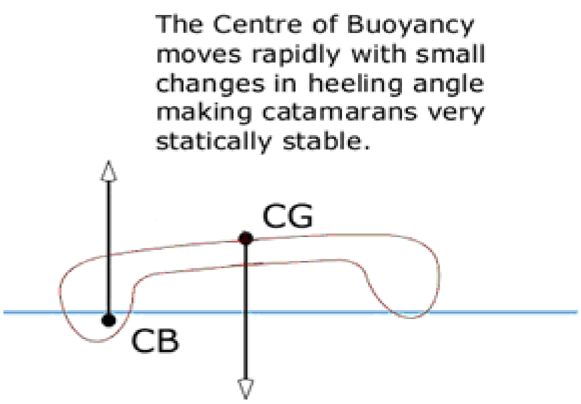


Figure 1.5. Position of the Centre of Buoyancy. (Ref. - **http://www.multihull-maven.com/Seaworthiness**)

Comfort in multihulls

This material was taken from the link: **http://www.multihull-maven.com/The_Multihull_Ride**

Though originally exploited for their speed, the last 50 years of development have proved that multihulls have benefits in comfort and particular in comfort in different weather conditions.

The wide beam and low displacement of multihulls makes their movement in a seaway quite different from the narrower beam and heavier displacement of most monohulls. For instance, multihulls do not roll as much.

When there is wave action, multihulls respond differently from monohulls. Because of the high buoyancy concentrated at the beam ends, multis are very 'stiff' in the rolling direction, riding the waves like a raft. Their reaction is short and quick and they do not have the exaggerated wallowing roll that can be very unpleasant in a monohull.

The other movements likely to cause much discomfort are heave and pitch from following or head seas. Both pitch and heave usually happen together. When beating into waves, pitching and heaving may be accompanied by slamming or pounding, which describes what happens when the boat crests a short, steep wave and makes a violent contact with the next one.

Some early catamaran designs pitched badly, their hull forms encouraging the nose up and down rocking called 'hobby -horsing'. Too much weight in the ends of the boat, too little reserve buoyancy in the bow and stern, Vee sectioned hulls aft, and too much hull rocker all combined to magnify this vice. Designers have since learned to draw catamarans & trimarans that have an easier response to waves, as comfortable as any other vessel.

Slamming, particularly from waves hitting the underside of the bridge deck, remains an enduring problem of catamarans. Although this problem can be designed out by having sufficiently high bridge deck clearance above the waterline.

Seaworthiness

The most important feature of any boat, its seaworthiness, is the most difficult one to assess. Seaworthiness is simply the capability of a boat to afford the crew safety and comfort in any condition. But it can take time before the seaworthiness of a new type of vessel is fully understood even by designers. Especially so, since there are infinite possible combinations of weather, sea and hazard, which negatively impact on a vessel and should be considered by designers.

Through the prolonged exposure of thousands of different crafts, the multihull design has matured through a progressive experience. Safety records over the years are second to none and consequently, catamarans and trimarans have earned their place in the mainstream of the boat market.

So far it can be said with total confidence that a multihull, as a type of vessel, is at least as safe in any condition as a monohull. Possibly multihulls are safer. Naturally, they have different strengths and weaknesses than monohulls in their “capability to afford comfort and safety in any conditions.” No boat is ever 100% seaworthy.

Multihulls in motion

The material was taken from the link: **http://www.multihull-maven.com/The_Multihull_Ride**

The movement of the boat changes with the course and boat speed. In this section you can see what makes a multihull so safe. A more seaworthy boat will have less movements in a seaway and conserve the energy and wellbeing of the crew. Besides barring enjoyment of a trip, seasickness commonly contributes to the cause of accidents. As too does crew exhaustion from long exposure to being thrown around in bad & harsh weather.

In very bad weather conditions, the behaviour of a boat becomes critical to its survival.

Every design of boat has its individual character at sea as even subtle differences in hull form, weight distribution and rig have an influence on the six directions of motion: roll, pitch, yaw; heave, surge and sway. However, characteristically there are some typical minor differences between catamarans and trimarans and major differences between multihulls and monohulls.

We will consider the differences according to those criterions.

Six principal motions (Six degrees of freedom) describe the motion of a ship in waves

A ship can be considered to have six degrees of freedom in its motion, i.e. it can move along any of six axes (see Figure 1.6).

The material has been taken from a source: "Maritime Dictionary"; the reference/ link is **http://www.m-i-link.com/dictionary/default.asp?term=heave**

Three of these involve translation:

- *surge* (forward/astern)
- *sway* (starboard/port)
- *heave* (up/down) and the other three rotation:
- *roll* (rotation about surge axis)

- *pitch* (rotation about sway axis)
- *yaw* (rotation about heave axis)

Will describe in this Chapter the definitions of those terms:

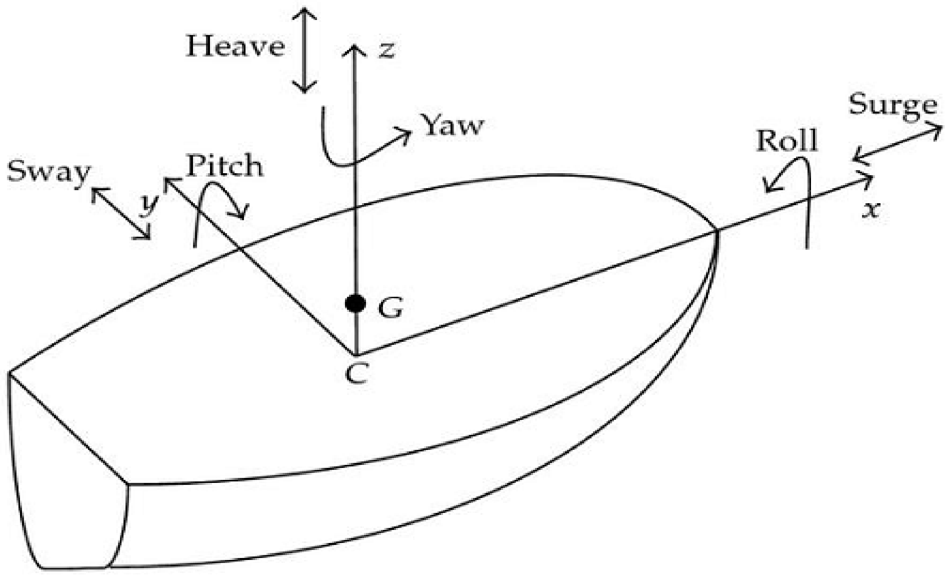


Figure 1.6. Ship schematic diagram showing the six degrees of freedom.

(Ref. - http://www.multihull-maven.com/Seaworthiness)

- HEAVE describes the vertical movement of the C.G. (C.G.-centre of gravity), up-and-down motion of a ship;
- PITCH describes the angular motion about the ships transverse axis; this causes the forward and aft ends of the ship to rise and fall repeatedly;
- ROLL describes the motion of a ship about her longitudinal axis; this causes the ship to rock from side to side;
- SWAY describes the "sliding" lateral, side-to-side motion of a ship in the horizontal plane;
- YAW describes the angular motion in the horizontal plane of a ship about her vertical axis; this causes the forward and aft ends of the ship to swing from left to right repeatedly;
- SURGE describes the "sliding" longitudinal or fore and aft movement of the C.G. of the ship after subtracting mean speed.

CHAPTER 2: CATAMARANS/ TRIMARANS

Multihulls: main issues & main concepts. Motions of monohulls.

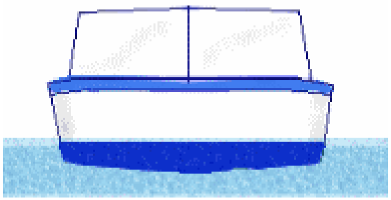
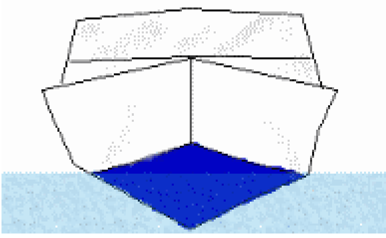
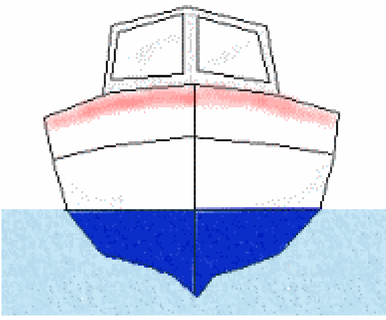
This Chapter will cover a comparison of monohulls, catamarans and trimarans. Will go little bit deeper into some key issues, such as: Performance, Safety, Handling, Comfort and Price.

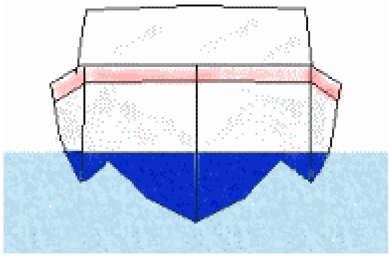
The material is based on the information taken from the following sources:

http://boatsafe.com/kids/022298hulls.htm

http://www.boatus.org/onlinecourse/reviewpages/boatusf/project/info1b.htm

We will start with a small introduction to different hull types-from mono to multi:

	**Flat bottom boat** - These types of hulls are less expensive to build and have a shallow draft (the part of the boat that's under the water). They can get up "on plane" ***** easily but unless the water is very calm they tend to give a rough ride because of the flat bottom pounding on each wave. They are also less stable and require careful balancing of cargo and crew. *** -** it means this boat can easily be ridden on top of the water at high speeds.
	**Vee bottom boat** - The vee bottom tends to have a sharper entry into the water which provides for a smoother ride in rough water, because it builds its buoyancy at a slower rate than the flat bottom boat. The only disadvantage with this type of hull is that it requires more power to achieve the same speed.
	**Round bottom boat** - This hull moves easily through the water, especially at slow speeds, due to the contours that this boat has. These hulls have a tendency to roll unless they are outfitted with a deep keel or stabilizers. The majority of boats these days uses this design.

	**Multi-hull boat** - two or more hulls attached closely together. The width provides greater stability. Each of the hulls may carry any of the above designs. The combination of hulls gives this type of boat excellent stability because there is more surface area underwater to keep the boat upright. Catamarans, trimarans, pontoon boats and some house boats use a multi-hull design.

(Ref. - http://boatsafe.com/kids/022298hulls.htm)

(Ref. - http://www.boatus.org/onlinecourse/reviewpages/boatusf/project/info1b.htm)

The "***sustention triangle***" is a commonly used device for characterizing ship types, see Figure 2.1. It is a conceptual device for understanding what makes the boat float. Traditional ships float because they are immersed in water and buoyed up by Archimedes' force. This is called "buoyant lift" and occupies the lower left corner of the triangle.

There are other ways to hold ships up. The reader may be familiar with hovercraft, for example, where the ship is lifted on a bubble of air. Hovercrafts are examples of "powered lift" craft, as depicted on the lower right corner of the triangle.

Another lift type one may be familiar with is "dynamic lift". A water ski works by dynamic lift. It does not float, but when pulled fast enough through the water it generates a good lift force and raises the entire payload up out of the water. Hydrofoils and hydroplanes are both dynamic lift craft.

(Ref. – **"Hull Form and Propulsor Technology for High Speed Sealift", revised: 13 February 1998, edited by Chris B. McKesson, PE**).

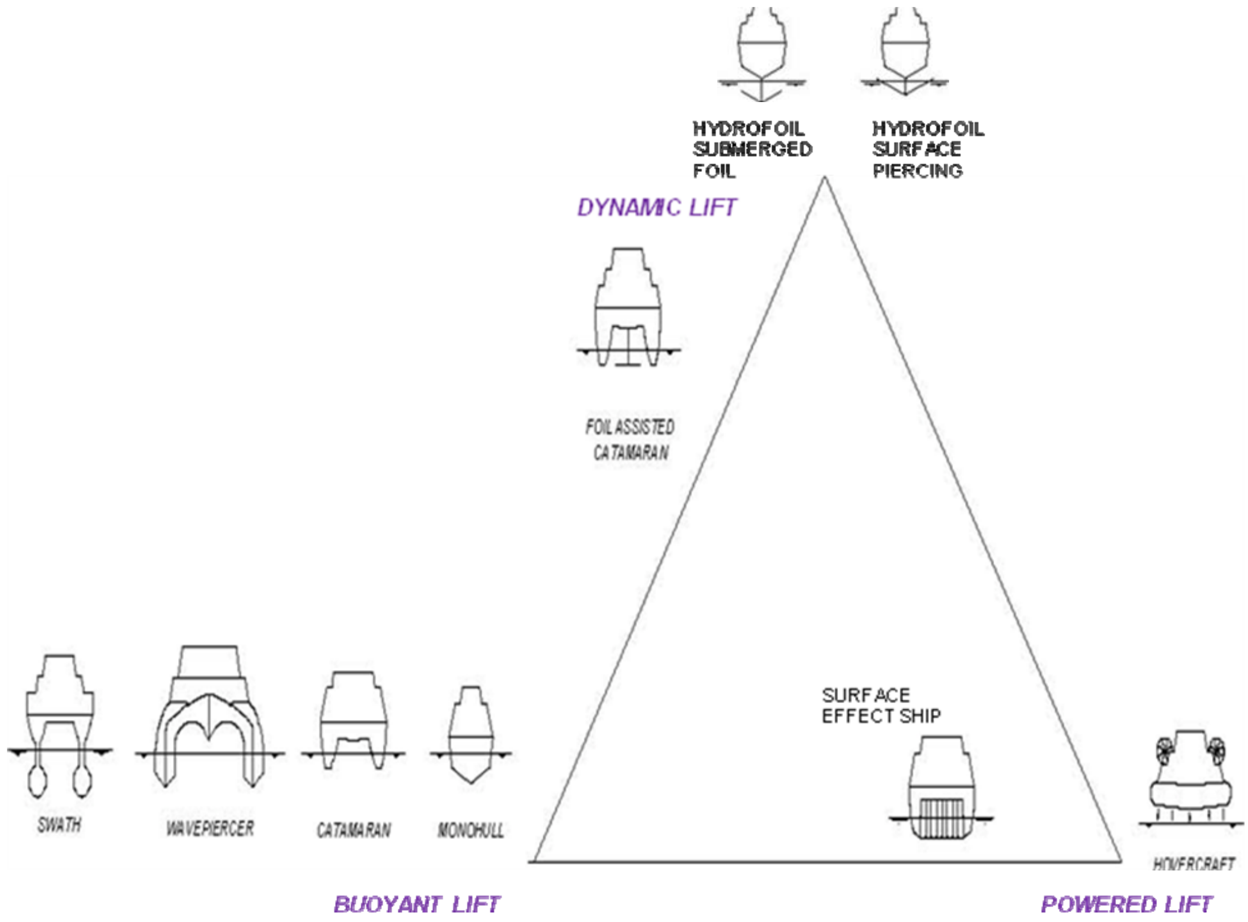


Figure 2.1. The "***sustention triangle***".

(Ref. – "**Hull Form and Propulsor Technology for High Speed Sealift", revised: 13 February 1998, edited by Chris B. McKesson, PE**).

Comparison to Monohulls

(Based on Ref. - **http://en.wikipedia.org/wiki/Trimaran**).

Multihulls have a number of advantages over comparable monohulls. Given two boats of the same length, the multihull has a shallower draft, a wider beam, less wetted area, and is able to fly more sail area. In addition, because of the righting moment provided by the wide beam, multihulls do not need the weighted keel that is required in monohulls.

As a result of the wide beam, the multihull vessel offers much better straight-line performance, is able to sail in shallower water, and maintains its stability in stronger winds. However, its wider beam requires more space to maneuver, so tacking can be trickier in confined areas and the narrower hulls provide less living space than an equivalently-sized monohull. Catamarans/trimarans also require more docking space. (Ref. - **http://en.wikipedia.org/wiki/Trimaran**).

Variations of trimarans and catamarans

SWATH (***Small waterplane area twin hull***), see Figure 2.2, is a twin-hull ship design that minimizes hull cross section area at the sea's surface. By minimizing the ship's volume near the surface area of the sea, where wave energy is located, a vessel's stability is maximized, even in high seas and at high speeds. The bulk of the displacement necessary to keep the ship afloat is located beneath the waves, where it is less affected by wave action.

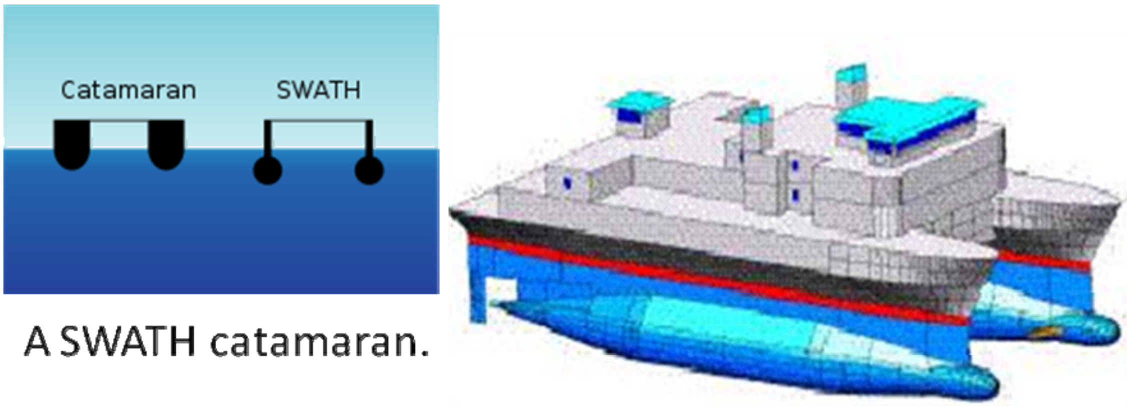


Figure 2.2. A SWATH example of catamaran's hull.
(Ref.- **http://en.wikipedia.org/wiki/SWATH)**

The twin-hull design provides a stable platform and large, broad decks. The main disadvantages of SWATH watercraft are that they are more expensive than conventional catamarans or monohulls, require a complex control system, have a deeper draft, and maintenance requirements are higher. One of the structural challenges is the split forces acting on the legs of the SWATH vessels (see Figure 2.3) in rough sea conditions.

Most SWATHs in operation today are designed for operations in moderate weather, but these vessels are not considered robust enough for North Sea operations. A heavier version of the SWATH for North Sea operations could be a concept for the future. A "Heavy-SWATH" vessel would most likely be a relatively expensive vessel to build relative to the payload, so if the concept shall have a North Sea application, the vessel will most likely operate in a market where the need for payload is low. (Ref. – **Doctoral Thesis of Erlend Hovland: "Evaluation of Vessel Concepts for the Subsea Operations in Northern Seas", UiS, Stavanger, Norway, 2007.)**

(Ref. - http://en.wikipedia.org/wiki/Multihull)

(Ref. - http://en.wikipedia.org/wiki/Small_waterplane_area_twin_hull)

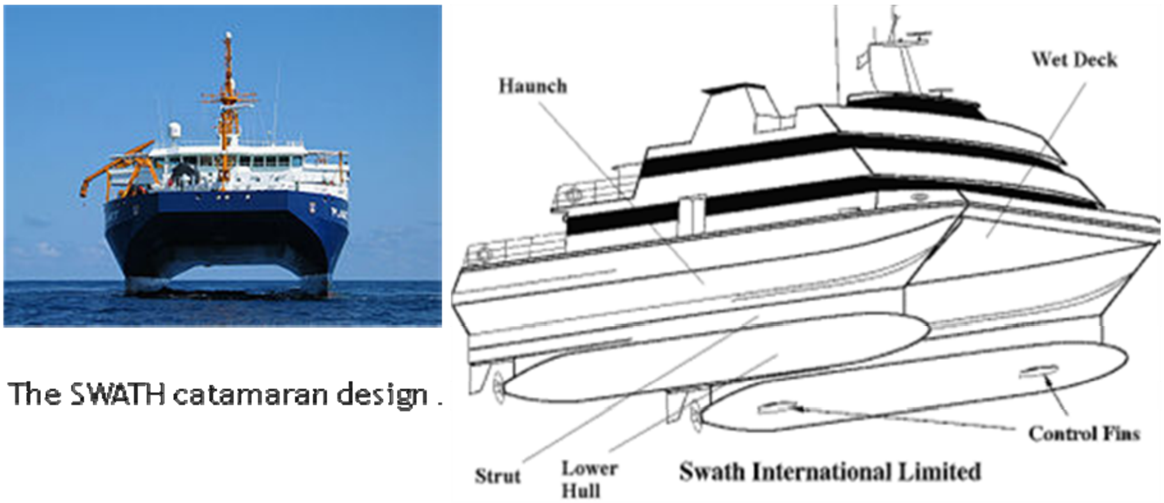


Figure 2.3. The SWATH design of the research catamaran.

(Ref. - http://en.wikipedia.org/wiki/Catamaran)

Pontoon boat or hydroairy ship

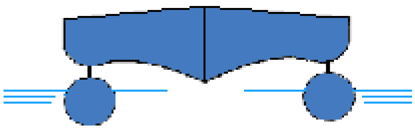


Figure 2.4. Hydroairy or Pontoon type (Ref. - http://en.wikipedia.org/wiki/Catamaran).

The *hydroairy catamran* see Figure 2.4, appears to be nothing more than an upgraded and enlarged pontoon boat with a formed and shaped underplatform. The general architecture is identical and pretty identical to SWATH vessel, consisting of two flotation hulls ("chambers"), joined by a load carrying platform, which carries the deck or superstructure.

These sorts of boats are cheap and easy to make, require no ballast, and thus have good performance. Although this design is almost exclusively restricted to power boats, it is still essentially a catamaran. No displacement is lost towards ballast, therefore yielding huge operational efficiencies.

CHAPTER 3:

THE ELASTO-DYNAMICAL THEORY OF MULTIHULLS IN NONLINEAR BEAM SEAS

Let's study little bit more deeply elasto-dynamical theory of multihulls in nonlinear beam seas.

The objective is to demonstrate that then exist analytical methods to study the beams connecting the hulls of multibody systems. Thus a combination of wave tank testing and analysis can be used to optimize the beam design.

The following part of the Chapter has been taken from magazine "Journal of Fluids and Structures", # 17 (2003) (pages 875–885). Researches, tests and conclusions under the considered ***elasto-dynamical theory of multihulls*** have been made at the Technical University Hamburg-Harburg, Germany (Mechanics and Ocean Engineering Department). The authors of researches are Kral R., Kreuzer E. And Schegel V.

The described information is referred and based on knowledges from the books:

- Kral, R., Kreuzer, E., 1999. Multibody systems and fluid-structure interactions with application to offshore structures. In: Multibody System Dynamics, Vol. 3.
- Kral, R., Kreuzer, E., Schlegel, V., 1997. Multibody systems in nonlinear waves. In: Proceedings of the Fourth International Symposium on Fluid–Structure Interaction, Aeroelasticity, Flow-induced Vibration and Noise. ASME, Dallas.
- Kreuzer, E. and Schiehlen, W., 1990. NEWEUL—Software for the generation of symbolical equations of motion. In: Schiehlen, W.,1990. Multibody Systems Handbook, Springer, Berlin.

A two-dimensional boundary integral approach with fully nonlinear boundary conditions on the free surface is used to investigate and to show the dynamic behaviour of multihulls in nonlinear beam seas. As example, a catamaran is used in this Chapter. Two hulls are connected by elastic beams. Beams and hulls are modelled as multibody systems.

Multihulls are rapidly becoming important in transportation of cargo, people, etc. Since such vessels cross open waters, sea keeping considerations are important. We will investigate the influence of the elasticity of the coupling between the hulls on the motion of the bihull-beam system. The connecting beams are modeled as a chain of rigid beams with rotational springs and dashpots in the joints in order to represent stiffness and damping.

The numerical treatment of the problem requires an efficient computation scheme for the solution of the flow problem. Compared with other methods the direct boundary-element method (BEM) offers several advantages for a specific application for the following reasons:

- All quantities of interest—either given or unknown—are located on the boundary of rigid connections between the bodies.
- Only nodes on the boundaries have to be considered, large deformations are easier to handle with BEM.
- High curvatures arise when the discrete model of the geometry is formulated, especially on the free surface and where the free surface meets floating bodies. According to Lagrangian BEM formulation, the density of nodes increases in regions of high curvatures
- Only the wetted parts of the surfaces of the structures have to be taken into account, in order to adapt the method to fixed or floating structures.
- The pressure distribution on the wetted surfaces is easily available for the force, which depends on a time, and loading moment of the structures.

Problem formulation: All real fluids are viscous and compressible. We will ignore less important effects to simplify the model. To solve the fluid flow problem usual assumptions of incompressibility and irrotational flow are made, (according to Newman, J.N. "Marine Hydrodynamics", Cambridge(1977)).

The following reasons are given for this assumption: floating bodies moving mainly with the waves cause negligible or no separation near the corners of the bodies, hence, viscosity has little effect on the flow. The compressibility of water is very small; therefore, the density of the fluid is not changed within the range of expected pressure differences.

We will start this discussion by looking on the Laplace's equation

$$\text{div}\, u = \nabla^2 \Phi = 0,$$

where $\boldsymbol{u}$ is the fluid velocity and Φ the corresponding velocity potential. The equation of motion of the fluid particles can be reduced to Bernoulli's equation

$$\frac{D\Phi}{Dt} = -gy - \frac{1}{\rho}p - \frac{|u|^2}{2} + v^T u,$$

where $\boldsymbol{g}$ is the gravitational acceleration, $\boldsymbol{y}$ is the vertical position of the considered point, $\boldsymbol{\rho}$ is the density of the fluid, and $\boldsymbol{p}$ is the pressure. In this formulation we must distinguish between the velocity vector of a fluid particle $\boldsymbol{u}$ and the velocity vector $\boldsymbol{v}$ of a point moving relative to the fluid.

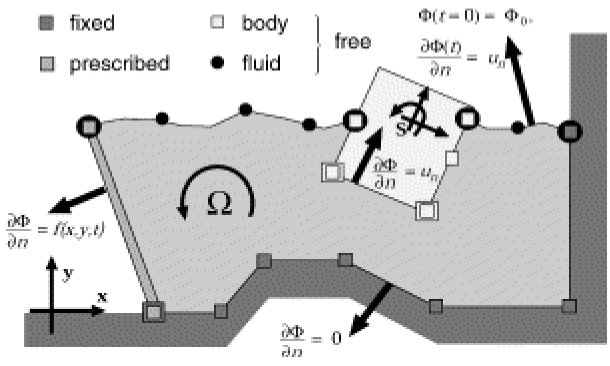


Figure 3.1. A schematic representation of the boundary conditions.

(Ref. - **Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures")**

The flow problem can be solved by transforming Laplace's equation into an integral equation on **Γ** the boundary of the considered domain **Ω,** see Figure 3.1.

The known and the unknown boundary conditions are rearranged into a set of linear equations

Ay=B.

Here, ***A*** is a general non-symmetric matrix.

B (the right part of the equation) is given by the following boundary conditions:

- at impermeable fixed boundaries, the velocity component in the normal direction to the boundary vanishes, $u_n=0$;
- at impermeable moving boundaries the motion, i.e. the normal velocity, is shown by a function f in space and time : $u_n=f(x,y,t)$;
- at the impermeable boundaries of the submerged parts of free floating bodies the time-dependent normal velocity is given by the normal direction of the time derivative of the nodal position $u_n=(dr/dt)n$, (it's calculated from the equations of motion of the rigid body);
- the free surfaces of the fluid are described by the fluid particles themselves. Therefore, the time-dependent velocity potential $\Phi(t)$ is given; thus, the normal velocity is $u_n=\partial\Phi(t)/\partial n$; The normal velocity is part of the boundary element solution.

On the impermeable boundary conditions the normal velocity u_n is known. There is no flow, therefore the normal velocity relative to these boundaries must vanish. The motion of the fluid particles at the free surfaces is described by a Lagrangian formulation, with ***v*** set equal to ***u*** in Bernoulli's equation.

$$\frac{D x_{fl}}{Dt} = \nabla\Phi = u, \quad \frac{D\Phi}{Dt} = -gy - \frac{1}{\varrho}p + \frac{|u|^2}{2}.$$

Here, $\boldsymbol{x}_{fl}=[x_{fl}\ y_{fl}]^T$ denotes the position vector of the fluid particles on the free surface;

$\boldsymbol{p}=\boldsymbol{p}_{amb}$ the pressure on the free surface;

$\boldsymbol{\Phi(t=0)=\Phi_0}$ the initial condition.

Kral, R., Kreuzer, E., Schlegel, V. have shown in the pages:"Multibody systems in nonlinear waves. In: Proceedings of the Fourth International Symposium on Fluid-Structure Interaction, Aeroelasticity, Flow-induced Vibration and Noise". Dallas, 1997, that even for *moderate forcing amplitudes nonlinearities have to be taken into account.*

The coupling beams of the catamaran, which have been modelled as a chain of seven rigid bodies coupled by hinges (cylindrical joints) are constrained by rotational springs and dash-pots (see Bockstedte, A., "Dynamik von Mehrrumpfbooten im Seegang.", Technical University Hamburg, Mechanics and Ocean Engineering, Hamburg,1998). Bockstedte investigated different discretizations for the elastic beams. It was found by investigating several models of the coupling beams that seven discrete links are sufficient for the considered configuration and frequency range * to get an accurate representation of the continuous elastic beam. The relative error of the first natural frequency of the seven link model compared to a continuous beam was found to be less than 2.5 percent.

For a catamaran with parameters as given below the first natural frequencies of the beam are 4.3, 11.8, and 23.8 Hz, whereas the forcing frequencies are of the order of 1 Hz.

The generalized coordinates of the discrete model shown in Fig. 3.2 are

$\boldsymbol{z_1=[x_{C1}\ y_{C1}\ \phi_1\ \phi_2\ \phi_3\ \phi_4\ \phi_5\ \phi_6\ \phi_7]^T}$

with respect to the centers of mass of the first hull.

All angles ϕ_i $(i= 1,7)$ are measured from the horizontal plane in the positive sense;

$\boldsymbol{z_2}$ is the time derivative of $\boldsymbol{z}_1$, i.e., $z_2 = \dot{z}_1$:

$$z_2 = [\dot{x}_{C1}\ \dot{y}_{C1}\ \dot{\varphi}_1\ \dot{\varphi}_2\ \dot{\varphi}_3\ \dot{\varphi}_4\ \dot{\varphi}_5\ \dot{\varphi}_6\ \dot{\varphi}_7]^T.$$

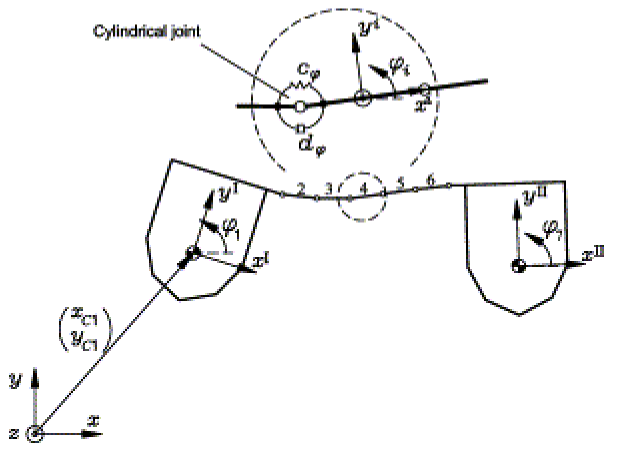


Figure 3.2. Positions of the coupling elements of the multibody system.

(Ref. - **Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures**")

The initial values are

$z_1(t=0)=[x_{C10}\ y_{C10}\ \phi_{10}\ \phi_{20}\ \phi_{30}\ \phi_{40}\ \phi_{50}\ \phi_{60}\ \phi_{70}]^T$

and

$z_2(t=0) = [\dot{x}_{C10}\ \dot{y}_{C10}\ \dot{\Phi}_{10}\ \dot{\Phi}_{20}\ \dot{\Phi}_{30}\ \dot{\Phi}_{40}\ \dot{\Phi}_{50}\ \dot{\Phi}_{60}\ \dot{\Phi}_{70}]^T.$

Results

All calculations of this Chapter are based on a two-dimensional mathematical representation of the wave tank (Fig.3.3) in the laboratory of the department of Mechanics and Ocean Engineering of the Technical University Hamburg, Germany.

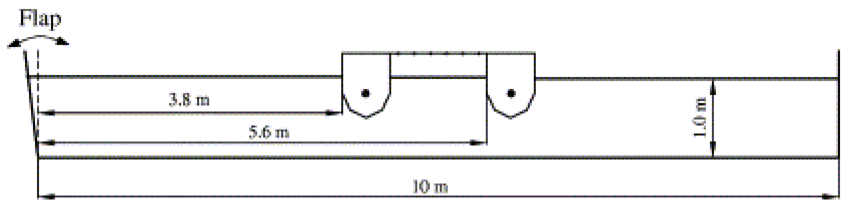


Figure 3.3. Initial position in the numerical wave tank.

(Ref. - **Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures**")

In order to simulate the dynamic behavior,the initial conditions should be prescribed. They should set to zero, because nonzero initial conditions on the free surface are difficult to prescribe.

The simulations were based on an idealized catamaran model, Fig.3.4 and Fig.3.5.

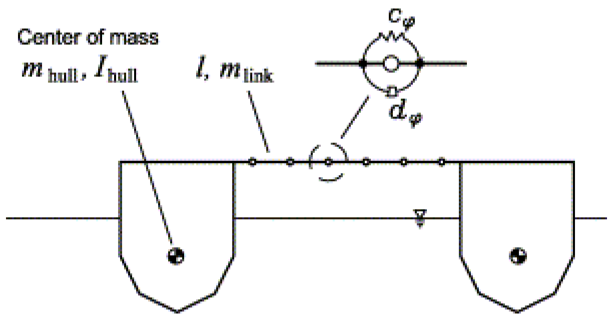


Figure 3.4. Parameters of the system

(Ref. - **Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures"**)

The mass of the floating bodies is m_{hull}**=237.3** kg, the moment of inertia is I_{hull}**=20** kgm^2 with respect to the centroid. The parameters of the connection between the hulls have been chosen to simulate a polypropylene plate of 5 mm thickness. The plate has a mass per section of m_{link}**=0.9 kg** and a length of l_{link}**=0.2 m**. The rotational springs have a stiffness of c_ϕ**=67.71 Nm**; the damping coefficient is d_ϕ**=0.1** Nms. The amount of damping is in the order of the expected material damping.

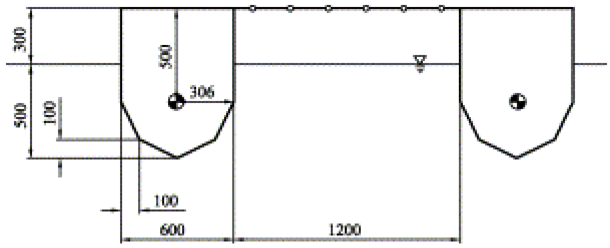


Figure 3.5. Geometry of the hulls.

(Ref. - **Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures"**)

Damping has a stabilizing effect on the hull.

To compensate for the roll moment (it was caused by the weight of the beam with a respect to the **CG*** of the hull) the **CM***of the hulls was moved 6 mm outwards from the **CB***. The beam vibrations caused the small ripples that can be seen in the plots of the roll angles of the hulls (Figs. 3.6 to 3.9).

CG*-center of gravity;

CM*-center of mass;

CB*-center of buoyancy.

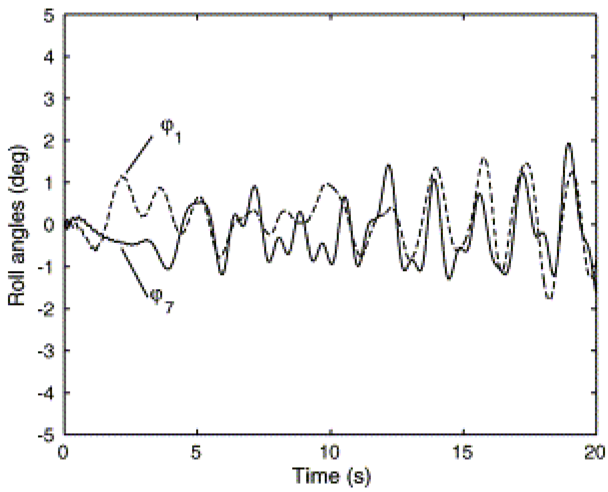


Figure 3.6. Roll motion of the hulls for a frequency of 1.2 Hz

(Ref. - **Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures**")

The dynamic behaviour of the floating multibody system was simulated for frequencies from 0.6 to 1.2 Hz. The energy in the tank was increasing as long as the flap is moving. The flap was stopped after 10 s.

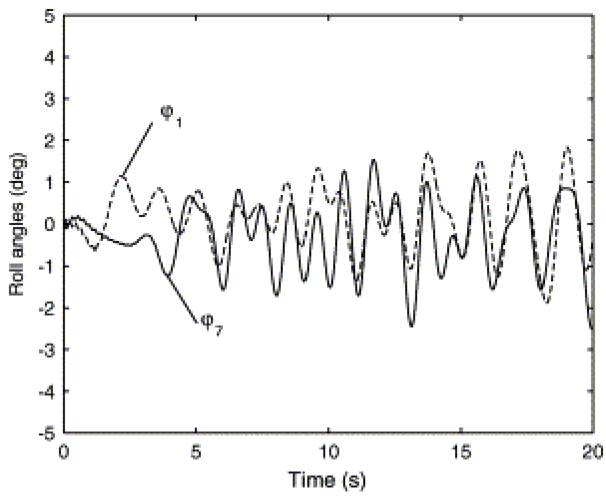


Figure 3.7. Roll motion of the hulls for a frequency of 1.0 Hz

(Ref. - **Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures**")

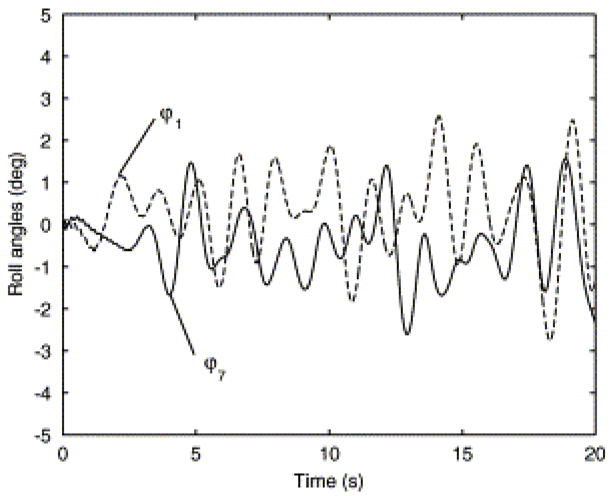


Figure 3.8. Roll motion of the hulls for a frequency of 0.8 Hz

(Ref. **- Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures**")

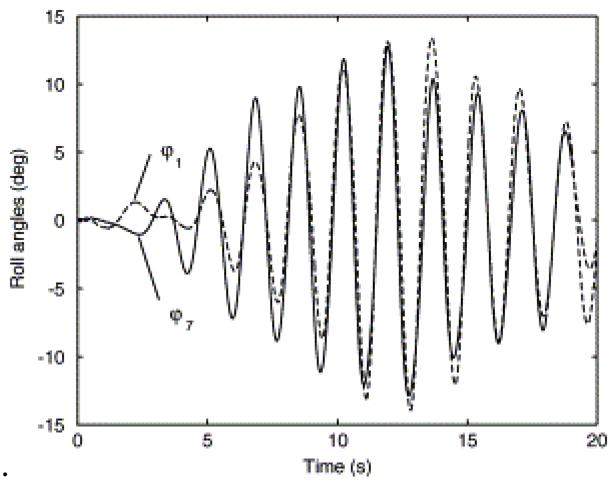


Figure 3.9. Roll motion of the hulls for a frequency of 0.6 Hz

(Ref. - **Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures**")

The roll angles are shown in Figs. 3.6 to 3.9, where Φ_1, and Φ_7 are the roll angles of the left and right hull, respectively.

In Fig. 3.10 the roll motion of the elastic catamaran is compared with the roll motion of the catamaran with rigid coupling. The wave height was reduced to about 30 mm, since the forcing wave frequency of 0.6 Hz is close to the heave natural frequency of 0.56 Hz of the rigid catamaran. The wavelength at this frequency is about twice the overall width of the model, hence, even for the rigid model significant roll amplitudes are observed.

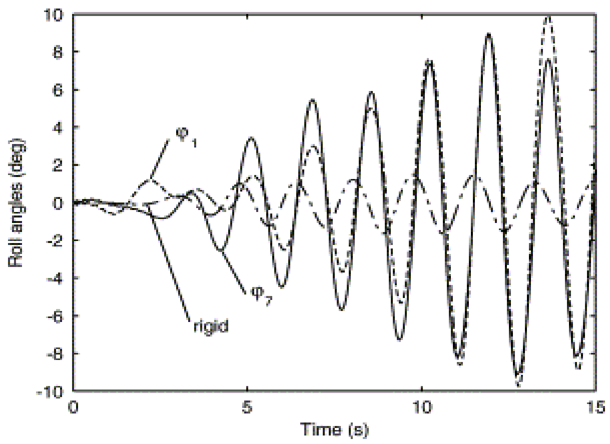


Figure 3.10. Roll motion of the elastic catamaran compared with a rigid model, 0.6 Hz, reduced wave height.

(Ref. - **Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures**")

As we see, the wavelength at frequency of 0.6 Hz is about twice the overall width of the model, hence, even for the rigid model significant roll amplitudes are observed.

From the test in a tank it is known that:

- The wavelengths vary from 1.08 m (at frequency of 1.2 Hz) to about 4.5 m (0.6 Hz). Hence the phase velocity of the waves is 1.30–2.60 m/s.
- The group velocity is half the phase velocity for deep water, i.e. wavelength up to 2.0 m in this case. The group velocity is approaching the phase velocity for shallow water.

In the Figs. 3.11 and 3.12 it is possible to see the deformation of the beam. Although the hulls are rolling in phase, the beam deformation is much bigger for 0.6 Hz compared with that for 0.8 Hz.

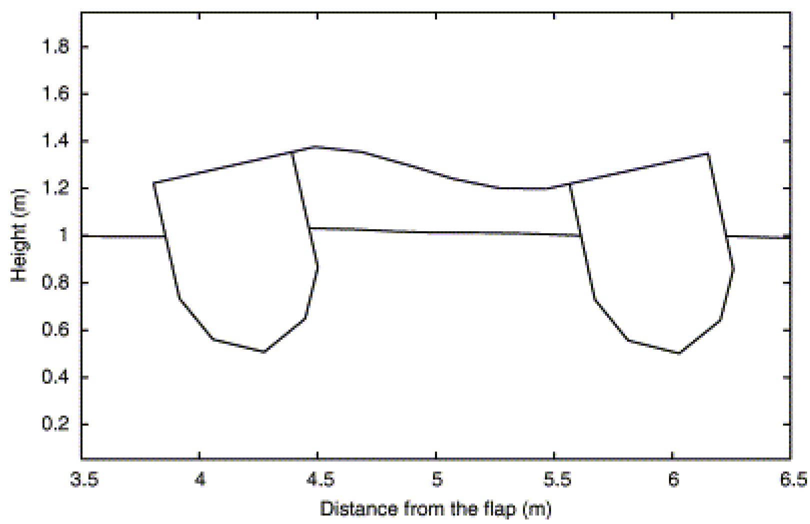


Figure 3.11. Deformation of the beam after 12.0 s & frequency 0.6 Hz

(Ref. - **Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures**")

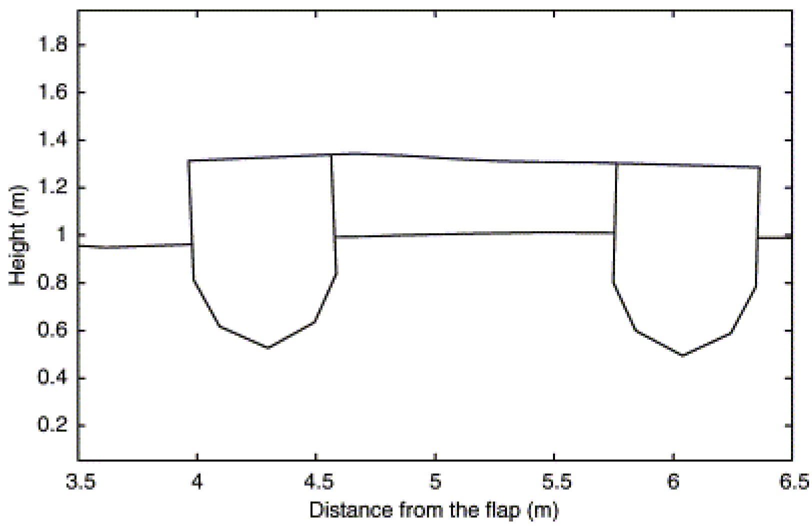


Figure 3.12. Deformation of the beam after 14.2 s & frequency 0.8 Hz

(Ref. - **Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures"**)

The internal moments in the joints can easily be calculated using the generalized coordinates. In Figure 3.13, the bending moments at the joints are plotted.

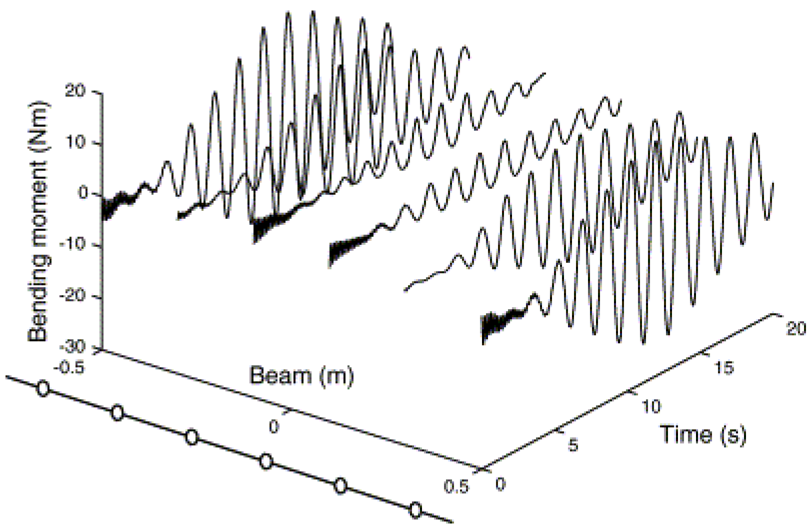


Figure 3.13. Internal bending moments for a frequency 0.6 Hz

(Ref. - **Kral R., Kreuzer E. and Schlegel V., 2003,"Journal of Fluids and Structures"**)

As we see from the Fig.3.13:

- the distance along the beam is measured from the center of the beam;
- the amplitudes are approx. symmetric with respect to the center-line;
- the bending moments have opposite signs due to different curvature of the beam at varying positions.

CONCLUSION

*This example considering the influence of a wave on a hull and its bending moment, shows the presence of deformations in the case of different wave frequencies and different factors of the external loading forces acting on multihulls.(**NOTE**: as a model the test example of the multihull (here-a catamaran) of the University of Hamburg (Germany) was used).*

As it seen from the elasto-dynamical theory of multihulls the elasticity of the beam connecting the hulls has a significant influence on the overall behavior of the system. The approach described here (namely the elasto-dynamical theory of multihulls in nonlinear beam seas) is not limited to twin-hulls, such as catamarans. It can easily be applied to trimarans or other multihulls.

The fluid dynamics are described by partial differential equations. The equations require integration with respect to space and time. Once the fluid flow has been calculated for the current time step using the boundary element method, the multibody and the fluid dynamics can be integrated with respect to time.

Thus the forces and moments in the elastic beams connecting the hulls can be found analytically and design optimizations can be carried out.

CHAPTER 4: RESISTANCE OF VESSEL'S MOTION

Resistance of catamarans and trimarans

In this chapter we will consider methods for calculation of the speed-ability of high-speed vessels, such as catamarans and trimarans.

The material is based on the information taken from the following source:
Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, Издательство НУК,Николаев, 2007.

A prominent feature of the development of modern ships and the construction of vessels of special purpose is the speed increase of the vessels, which is provided mainly due to increasing capacity of the main engines and due to improvement of the propulsion qualities of the vessels.
Also it's important to remember, that the most real opportunity to essential increasing the speed qualities is due to a reduction of the resistance to movement in water and due to increasing the effectiveness of vessel's propellers.

Decrease in the resistance of the displacement is reached by the selection of an optimum relationships of the main dimensions and of the block coefficients of the vessel. Artificial methods of decreasing the resistance are additionally used. They are based on different methods (elastic coatings, polymers), and also on creation of artificial cavitation.
The features of the calculation of the propulsive quality of high-speed vessels in comparison with a traditional water displacement vessel are the calculation of resistance to movement and calculations of drivers and definition of the main parameters of the devices providing dynamic maintenance of the vessels.

Resistance of multihulls on still water.

Components of the resistance.

Features of the water's resistance to motion are defined by the arrangement of the hulls and by the geometry of the subsea part of the multihull. These factors differently influence on the components of resistance of such vessels. At the same time some dimensions can be even disregarded, because of the small number. They can be neglected. (It will be appreciable below in the given chapter).
At usual distances between the hulls and at the most widespread geometry of these hulls it is possible to simplify the division of the resistance of a displaced multihull into the resistance of friction, resistance of the form and the wave resistance.
At usual modelling experiments the two last components: the resistance of the form and the wave resistance (as well as for monohulls) should be combined in one component called the residual resistance.

Resistance of a catamaran with a cruiser stern.

The approximate calculation of the water resistance to a catamaran's motion of this type can be found by using the data from model tests. Catamarans for relevant model tests should be with symmetric hulls, V-shaped frames and with a cruiser stern (see Figure 4.1).

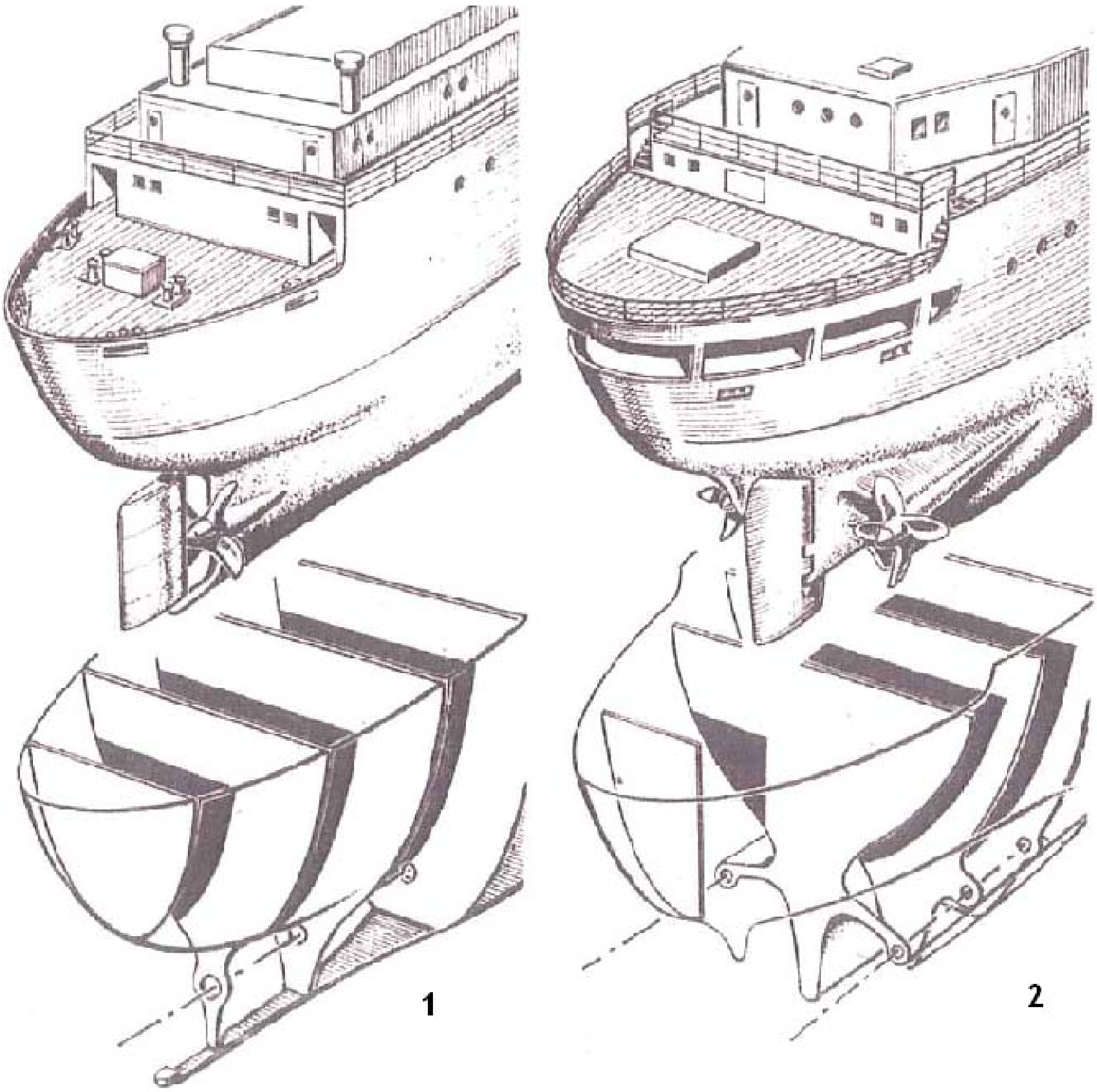


Figure 4.1. A cruiser stern.

(Ref. – http://www.seaship.ru/formbody.htm, "Features of the form of the vessel hull").

A hull with a double-screw has a V-shaped stern below a constructive waterline (CWL); and a one-screw hull has the U-shaped form of the hull, It is necessary to design the correct form of the stern for receiving as much as possible favorable conditions of a flow in the area of the rowing screw.

The main advantage of the cruiser stern is the much larger amount of deck space available. In the cruiser stern area frames are carried out in a form, that they cross a constructive waterline very flatly. That means, if the draught of the vessel will be insignificantly increased (will get a trim by the stern), the waterline should not become too full and resistance of the motion should not increase.

The main dimensions and characteristics of models are shown in Table 4.1. (Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, Издательство НУК,Николаев, 2007).

Номер модели	B_1	T	$L_{ВЛ}$	V_1, м^3	Ω_1, м^2	$L_{ВЛ}/B_1$	B_1/T	$\Omega_1/V_1^{2/3}$	$\delta_{ВЛ}$	$\varphi_{ВЛ}$	$\beta_{ВЛ}$	$\alpha_{ВЛ}$
	м											
1	1,072	0,410	3,90	0,823	4,66	3,63	2,62	5,33	0,482	0,578	0,833	0,822
		0,425	4,01	0,871	4,80	3,73	2,53	5,27	0,477	0,572	0,835	–
		0,477	4,05	1,044	5,28	4,06	2,25	5,12	0,470	0,550	0,855	–
2	0,75	0,33	3,99	0,502	3,80	5,32	2,25	6,03	0,504	0,605	0,833	0,819
		0,405	4,03	0,679	4,42	5,37	1,85	5,75	0,555	0,643	0,863	–
		0,455	4,06	0,811	4,85	5,40	1,65	5,57	0,585	0,665	0,880	–
3	0,535	0,240	3,95	0,238	2,70	7,40	2,23	7,02	0,470	0,565	0,833	0,820
		0,325	4,04	0,380	3,54	7,55	1,64	6,75	0,540	0,618	0,873	–
		0,410	4,08	0,540	4,34	7,63	1,30	6,53	0,603	0,672	0,897	–
5	0,535	0,240	3,95	0,282	2,73	7,40	2,23	6,35	0,557	0,670	0,833	0,820
		0,325	4,03	0,439	3,45	7,53	1,64	5,98	0,627	0,718	0,873	–
		0,410	4,08	0,604	4,15	7,63	1,30	5,83	0,677	0,755	0,897	–
6	0,535	0,240	3,98	0,328	2,93	7,43	2,23	6,18	0,643	0,772	0,833	0,820
		0,325	4,04	0,498	3,65	7,55	1,64	5,78	0,708	0,810	0,873	–
		0,410	4,08	0,674	4,33	7,63	1,30	5,62	0,752	0,838	0,897	–

Table 4.1. The main dimensions and the basic characteristics of catamarans with a cruiser stern. (Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК,Николаев, 2007).

NOTE: Номер модели - Item (The Model).

In Table 4.1 the following symbols are used: B_1 - is the width of one hull; T – is the draft of the multihull (catamaran in this case); $L_{ВЛ}$ – is the length at waterline (WL); V_1 – is the submerged volume of one hull; Ω_1 **-** is the area of the wetted surface of one hull; $\delta_{ВЛ}$, $\alpha_{ВЛ}$, $\beta_{ВЛ}$, $\varphi_{ВЛ}$ – are the block coefficient, the waterline coefficient, the coefficient of the submerged part of a midship frame and the prismatic coefficient respectively.

Will define all these coefficients below:

(Ref. - http://en.wikipedia.org/wiki/Hull_ (watercraft))

- $\delta_{BЛ}$ - the block coefficient – is the volume (V_1) divided by the LWL x BWL x T. If you draw a box around the submerged part of the ship, it is the ratio of the box volume occupied by the ship. It gives a sense of how much of the block defined by the L_{pp}, beam (B_1) & draft (T) is filled by the hull. Full forms such as oil tankers will have a high $\delta_{BЛ}$, where fine shapes such as sailboats will have a low $\delta_{BЛ}$.

Length at the waterline (LWL) ($L_{BЛ}$) is the length from the forward most point of the waterline measured in profile to the stern-most point of the waterline.

Beam or breadth (B_1) is the width of the hull. (ex: BWL is the maximum beam at the waterline).

Draft (***d***) or *(T)* is the vertical distance from the bottom of the hull keel to the waterline.

Length Between Perpendiculars (*LBP or LPP*) is the length of the summer load waterline from the stern post to the point where it crosses the stem.

$$\delta_{BЛ} = \frac{V_1}{L_{pp} \cdot B \cdot T}$$

- $\alpha_{BЛ}$ - the waterplane coefficient - is the waterplane area divided by L_{pp} x B. The waterplane coefficient expresses the fullness of the waterplane, or the ratio of the waterplane area to a rectangle of the same length and width. A low $\alpha_{BЛ}$ figure indicates fine ends and a high $\alpha_{BЛ}$ figure indicates fuller ends. High $\alpha_{BЛ}$ improves stability as well as handling behavior in rough conditions.

$$\alpha_{BЛ} = \frac{A_w}{L_{pp} \cdot B}$$

- $\beta_{BЛ}$ - the midship coefficient - is the cross-sectional area A_m divided by beam x draft. It displays the ratio of the largest underwater section of the hull to a rectangle of the same overall width and depth as the underwater section of the hull. This defines the fullness of the underbody. A low $\beta_{BЛ}$ indicates a cut-away mid-section and a high $\beta_{BЛ}$ indicates a boxy section shape.

$$\beta_{BЛ} = \frac{A_m}{B \cdot T}$$

- $\varphi_{BЛ}$ - the prismatic coefficient - is the volume (V_1) divided by L_{pp} x A_x. It displays the ratio of the underwater volume of the hull to a rectangular block of the same overall length as the underbody and with cross-sectional area equal to the largest underwater section of the hull. This is used to evaluate the distribution of the volume of the underbody. A low $\varphi_{ВЛ}$ indicates a full mid-section and fine ends; a high $\varphi_{ВЛ}$ indicates a boat with fuller ends. High-speed hulls tend towards a higher $\varphi_{ВЛ}$. Efficient displacement hulls travelling at a low Froude number will tend to have a low $\varphi_{ВЛ}$.

$$\varphi_{ВЛ} = \frac{V_1}{L_{pp} \cdot A_m}$$

NOTE : $\varphi_{ВЛ} = \delta_{ВЛ} / \beta_{ВЛ}$

The material was taken from the source (***Ref. http://en.wikipedia.org/wiki/Hull_ (watercraft)***).

It will be considered, that the resistance of a double-hull is connected to the resistance of the single hull as it's shown below:

$$R=2 R_F + 2k_{VP} R_{VP} + 2k_W R_W,$$

where R_F, R_{VP}, R_W - are the resistance of friction, the form resistance and the wave resistance of the single hull respectively; k_{VP} and k_W are found experimentally.

The representation of the formula above is caused by considering the resistance coefficient of the single hull of a catamaran vessel as shown in the formula below:

$$C_K= C_F + k_{VP} C_{VP} + k_W C_W \ ,$$

where C_F, C_{VP} and C_W - are the coefficients (of the resistances of friction, the form, the waves), which are related to the surface of a single hull and which can be calculated as:

- The coefficient of the friction resistance C_F without taking into account any mutual influence of multi hulls - according to formula of Prandtl – Shlihtyng is *) :

$$C_F = \frac{0{,}455}{(\lg Re)^{2{,}58}};$$

where ***Re*** - the Reynolds number.

****)*** **-** the value of ***CF(Re)*** is possible to get from Table 4.2:

$Re \cdot 10^{-7}$	$C_F \cdot 10^3$	$Re \cdot 10^{-8}$	$C_F \cdot 10^3$	$Re \cdot 10^{-9}$	$C_F \cdot 10^3$
1,00	3,00	1,00	2,13	1,00	1,57
1,25	2,90	1,25	2,06	1,25	1,53
1,50	2,82	1,50	2,01	1,50	1,49
1,75	2,75	1,75	1,97	1,75	1,46
2,00	2,69	2,00	1,94	2,00	1,44
2,50	2,60	2,50	1,88	2,50	1,40
3,00	2,53	3,00	1,83	3,00	1,37
3,50	2,48	3,50	1,80	3,50	1,35
4,00	2,43	4,00	1,77	4,00	1,33
4,50	2,38	4,50	1,74	4,50	1,31
5,00	2,35	5,00	1,71	5,00	1,29
5,50	2,32	5,50	1,69	5,50	1,28
6,00	2,29	6,00	1,67	6,00	1,27
6,50	2,26	6,50	1,65	6,50	1,26
7,00	2,24	7,00	1,64	7,00	1,25
7,50	2,22	7,50	1,63	7,50	1,24
8,00	2,20	8,00	1,62	8,00	1,23
8,50	2,18	8,50	1,61	8,50	1,22
9,00	2,16	9,00	1,60	9,00	1,21
9,50	2,14	9,50	1,59	9,50	1,20

Table 4.2. The friction coefficient C_F according to formula Prandtl – Shlihtyng
(Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК,Николаев, 2007).

- the coefficient of the form resistance C_{VP} can be found by using graphs of the residual resistance of single hulls (Figures 4.3 and 4.4); at Fr=0,2 the coefficient of the form resistance equals to a residual resistance C_R:

$$C_{VP} = C_R\left(\text{Fr} = 0{,}2;\ l_1 = \frac{L}{B_1};\ \varphi\right);$$

where $\varphi = \varphi_{ВЛ}$ - is the prismatic coefficient; Fr - is the Froude number.

- the coefficient of the wave resistance C_W of a single hull can be found by using graphs (Figures 4.3 and 4.4) :

$$C_W = C_R(\text{Fr};\ l_1;\ \varphi) - C_{VP}(\text{Fr} = 0{,}2;\ l_1;\ \varphi).$$

The analysis of the results of the tests has determined that the key parameters which define the parameter C_K are: the relative length of the single hull L/B_1, the relative size of the transverse clearance $2\bar{b} = 2b / L_{ВЛ}$, the ratio of the width to draft of the single hull B_1/T, the block coefficient $\delta_{ВЛ}$ and the Froude number

$$Fr = \frac{\upsilon}{\sqrt{gL}},$$

where υ - is the speed of the vessel, m/s; g - is the acceleration due to gravity, kg/m^3; L - is the length of the ship at the water line level, m.

(***NOTE:*** The transverse (diametric) clearance b is the distance from the centreline of the single hull up to catamaran's centreline, see Figure 4.2.

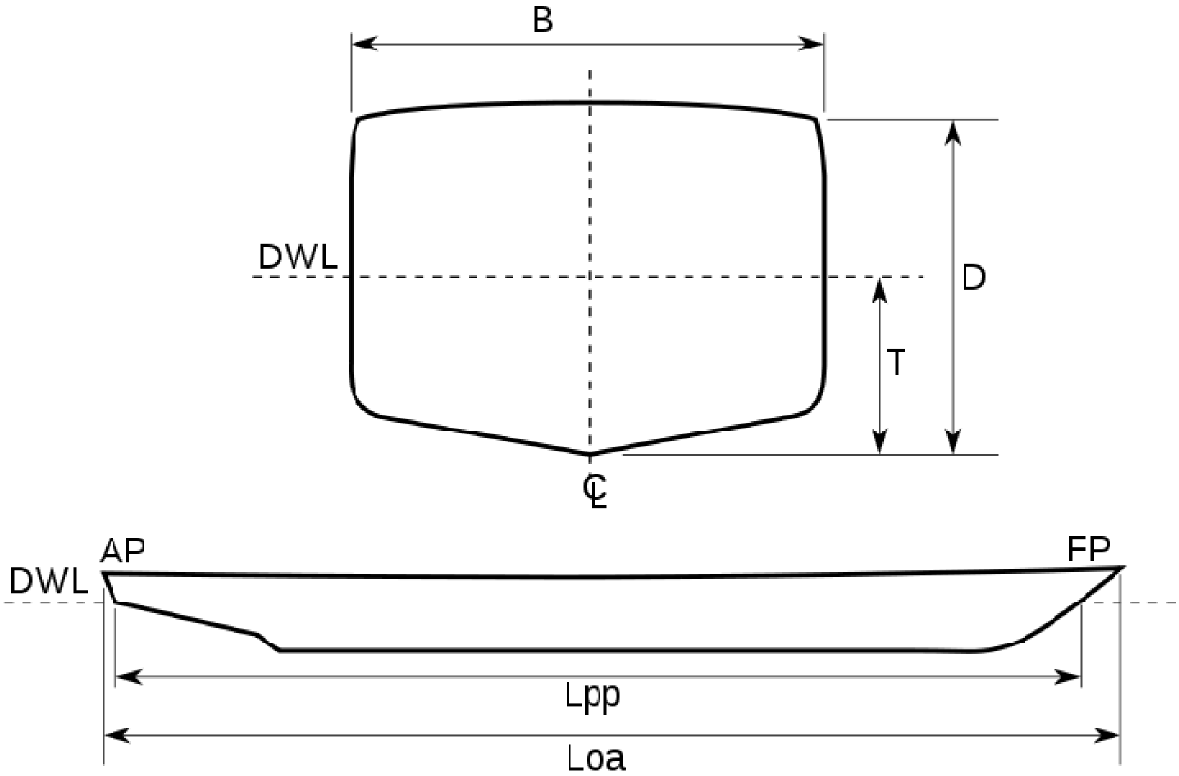


Figure 4.2. Ship main dimensions. (Ref. - **http://ru.wikipedia.org/wiki/)**

This analysis has defined the coefficients of the parameters which are listed above and it gives the formulas:

$$k_{VP} = k_{VP\,L/B} k_{VP\,\delta} k_{VP\,B/T};$$
$$k_{W} = k_{W\,L/B} k_{W\,\delta}\, k_{W\,B/T},$$

where

$$k_{VP\,L/B}\left(\frac{L}{B_1}; 2\bar{b}\right) \text{ and } k_{W\,L/B}\left(\frac{L}{B_1}; 2\bar{b}\right)$$

- are the impact coefficients depending on the diametric clearance $2\bar{b}$ and the relative length ***L/B₁***:

$$k_{VP\,\delta}\left(\delta;\,2\bar{b}\right) \text{ and } k_{W\,\delta}\left(\delta;\,2\bar{b};\,\mathrm{Fr}\right)$$

- are the impact coefficients depending on the block coefficient ***δ***, the diametric clearance $2\bar{b}$ and the Froude number ***Fr***:

$$k_{VP\,B/T}\left(\frac{B_1}{T};\,2\bar{b}\right) \text{ and } k_{W\,B/T}\left(\frac{B_1}{T};\,2\bar{b};\,\mathrm{Fr}\right)$$

- are the impact coefficients depending on the relative width of the single hull B_1/T , the diametric clearance $2\bar{b}$ and the Froude number ***Fr***.

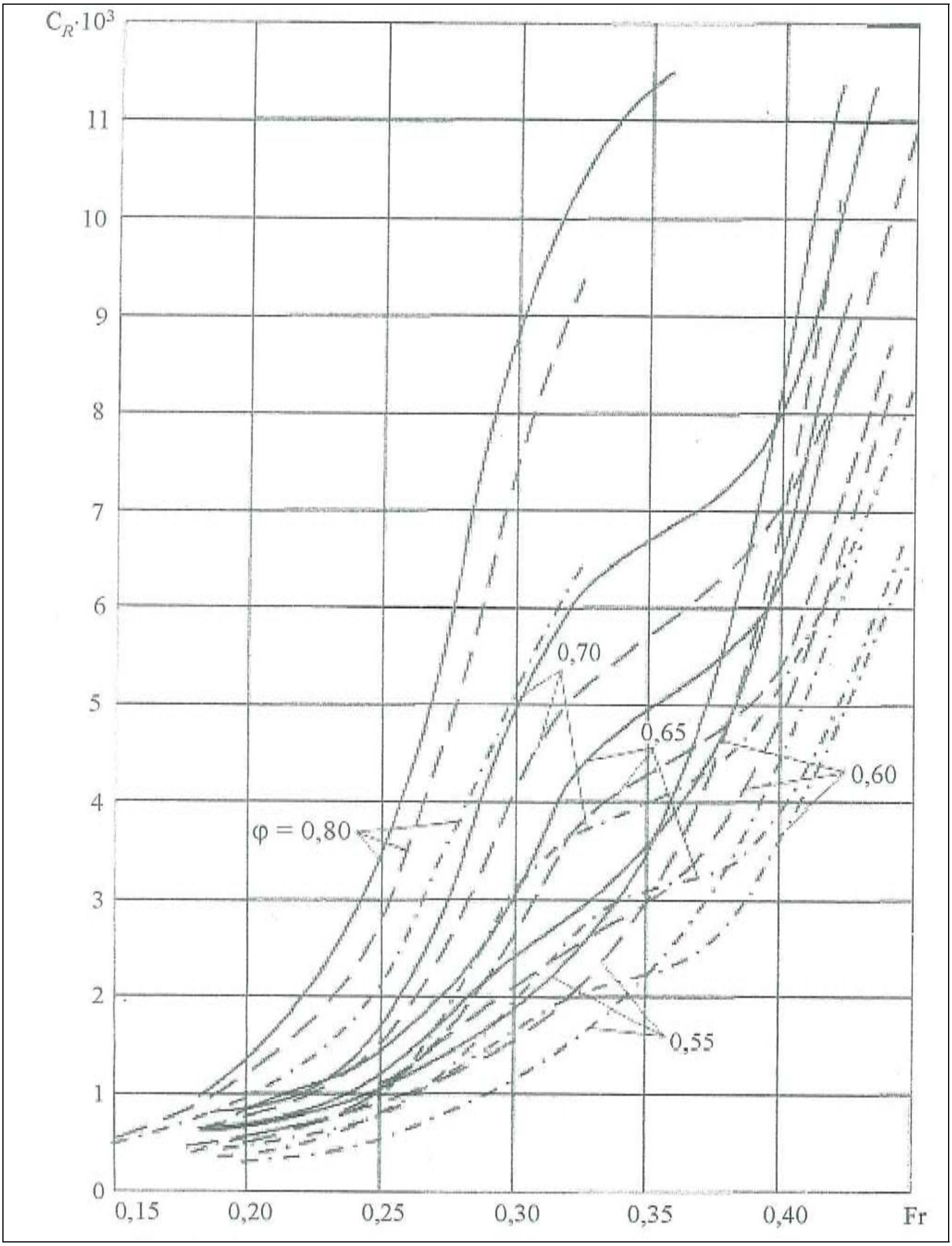


Figure 4.3. The residual resistance C_R of the single hull of a catamaran

(Ref. - Сліжевський Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК,Николаев, 2007) :

——— – l_1 = 4,0; – – – – – 4,5; –·–·–·– – 5,0

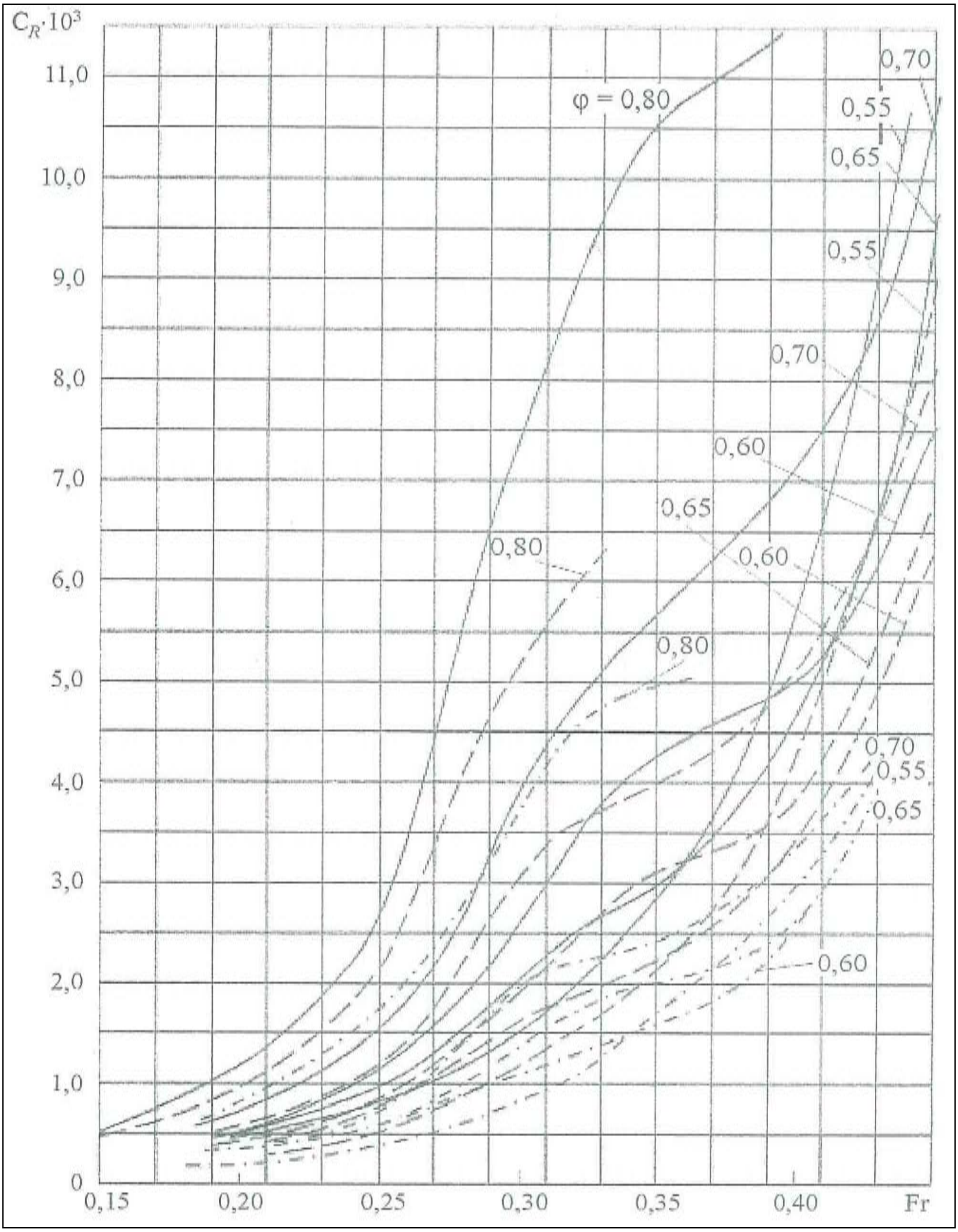


Figure 4.4. The residual resistance C_R of the single hull of a catamaran

(Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК,Николаев, 2007) :

$- - - - - l_1 = 6{,}0;$ ——— $- 7{,}0;$ –·–·–·– $- 8{,}0$

The coefficients can be defined by using experimental graphs $k_{VP\ L/B}$, $k_{VP\ B/T}$ and $k_{VP\ \delta}$ (Figure 4.5); $k_{W\ L/B}$, $k_{W\ \delta}$ and $k_{W\ B/T}$ (Figures 4.6 and 4.7).

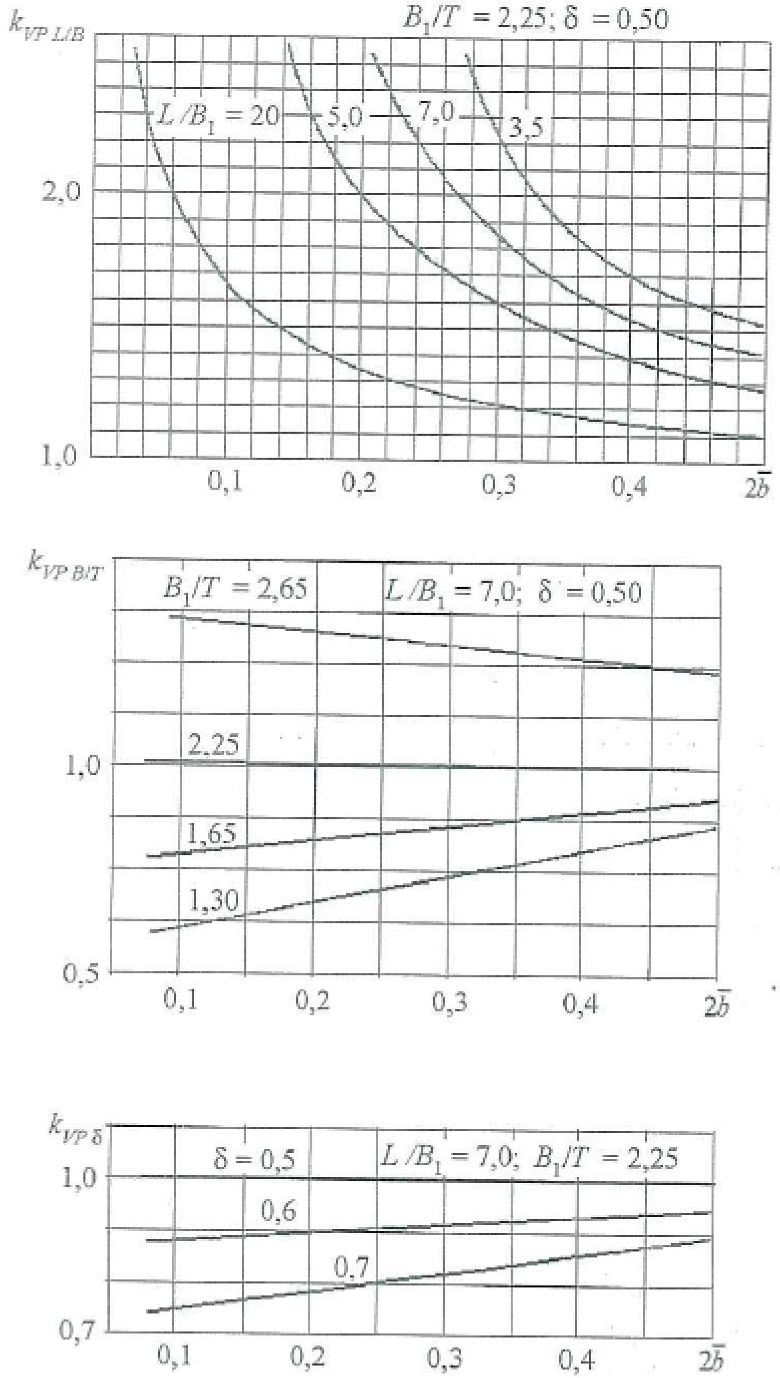
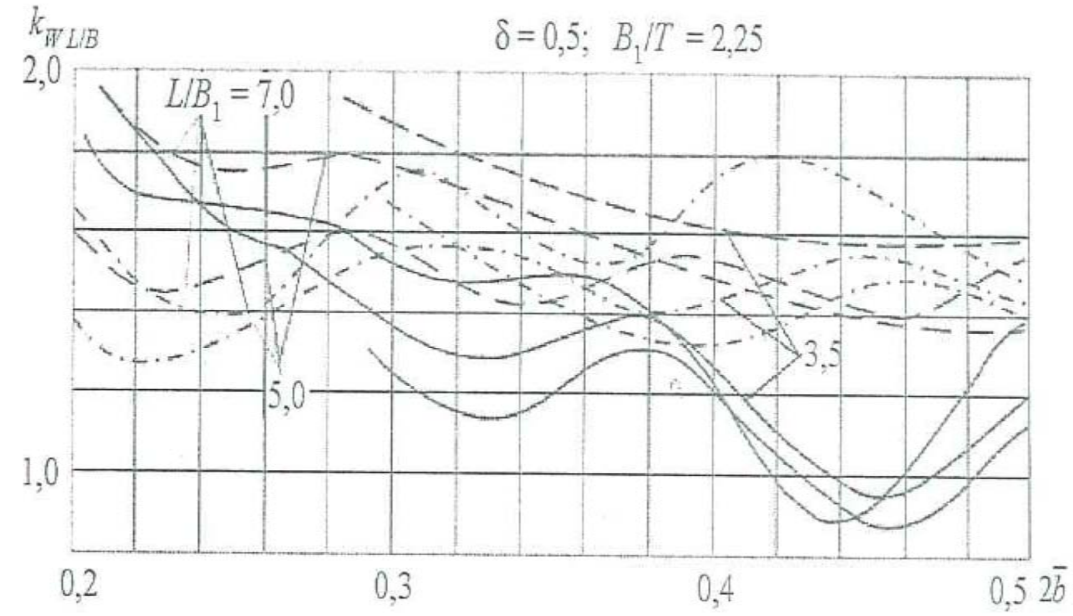
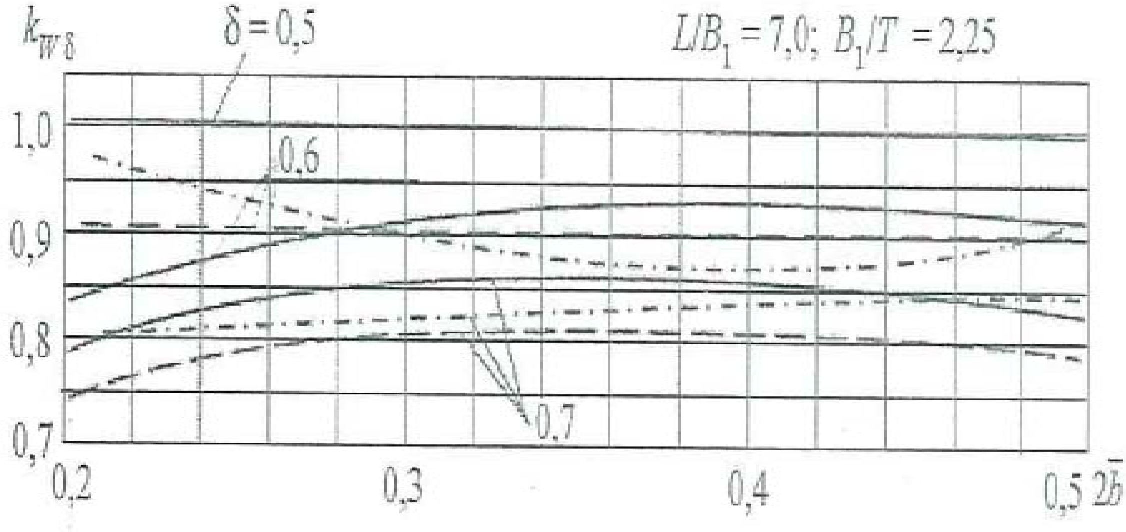


Figure 4.5. The impact coefficients of the form resistance depending on the diametric clearance $2\bar{b}$, the relative length L/B_1, the block coefficient δ and the relative width B_1/T. (Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).





<u>Legend</u>: see next page.

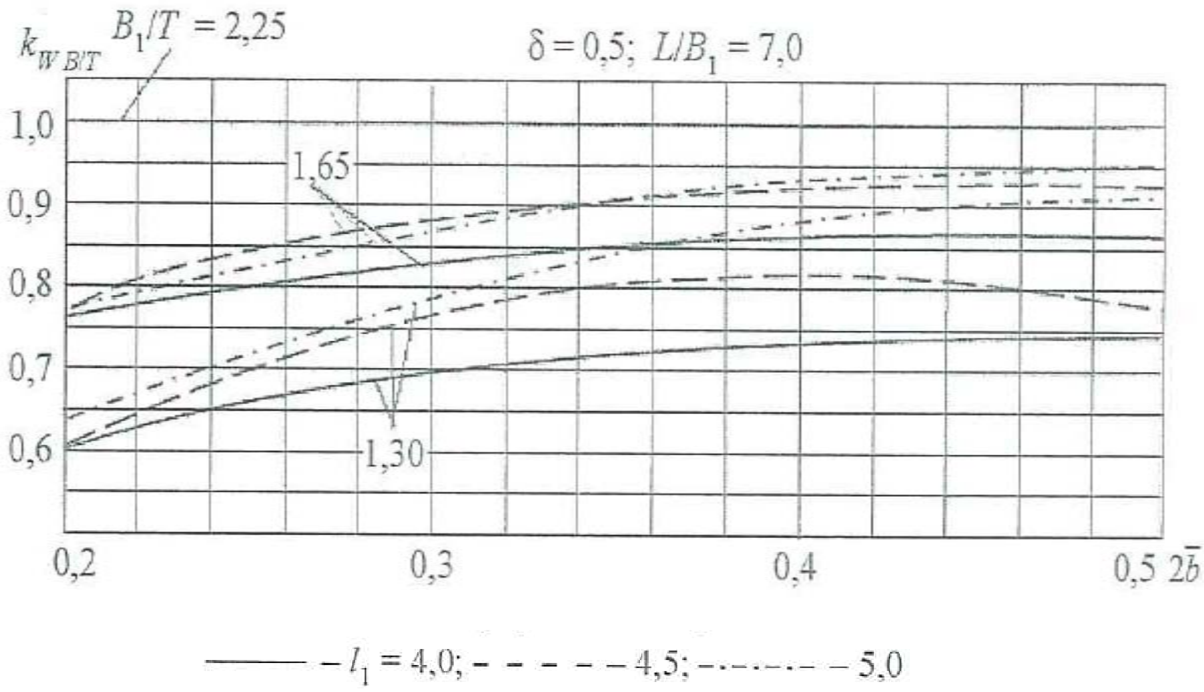
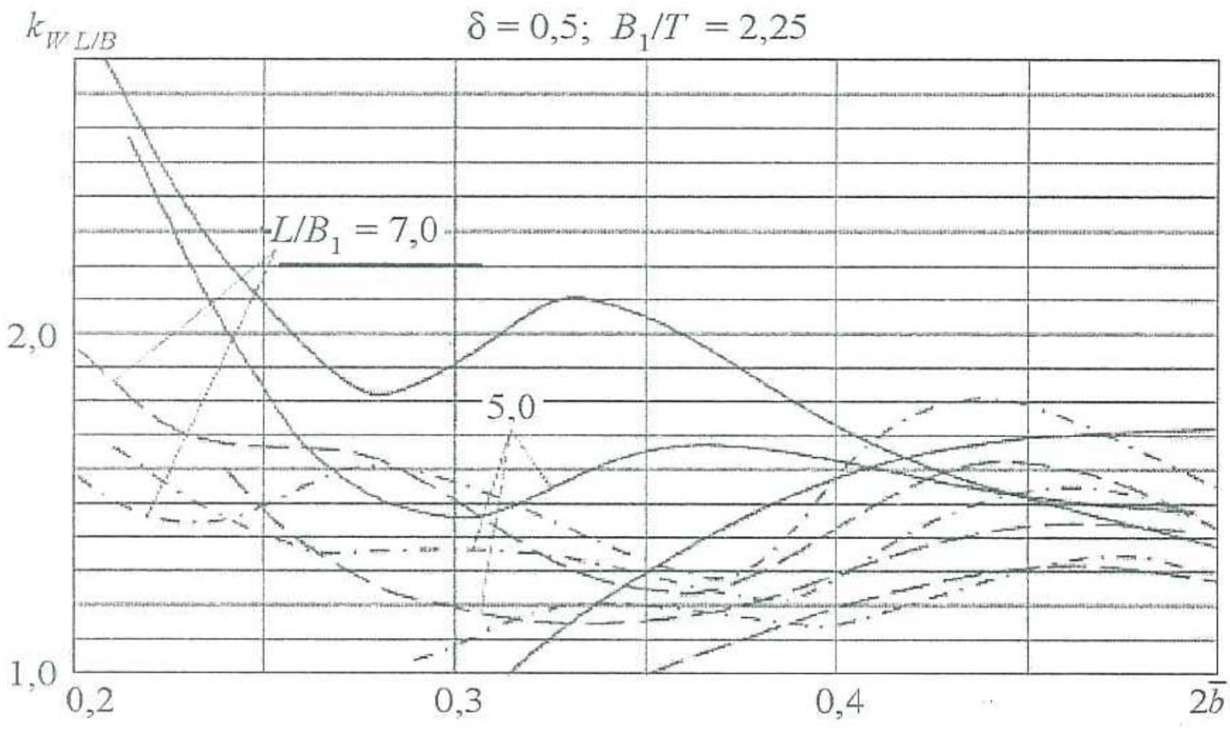


Figure 4.6. The impact coefficients of the wave resistance depending on the diametric clearance $2\bar{b}$, the relative length $\boldsymbol{L/B_1}$, the block coefficient $\boldsymbol{\delta}$ and the relative width $\boldsymbol{B_1/T}$ (Ref. - <u>**Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007**</u>).



<u>Legend</u>: see next page.

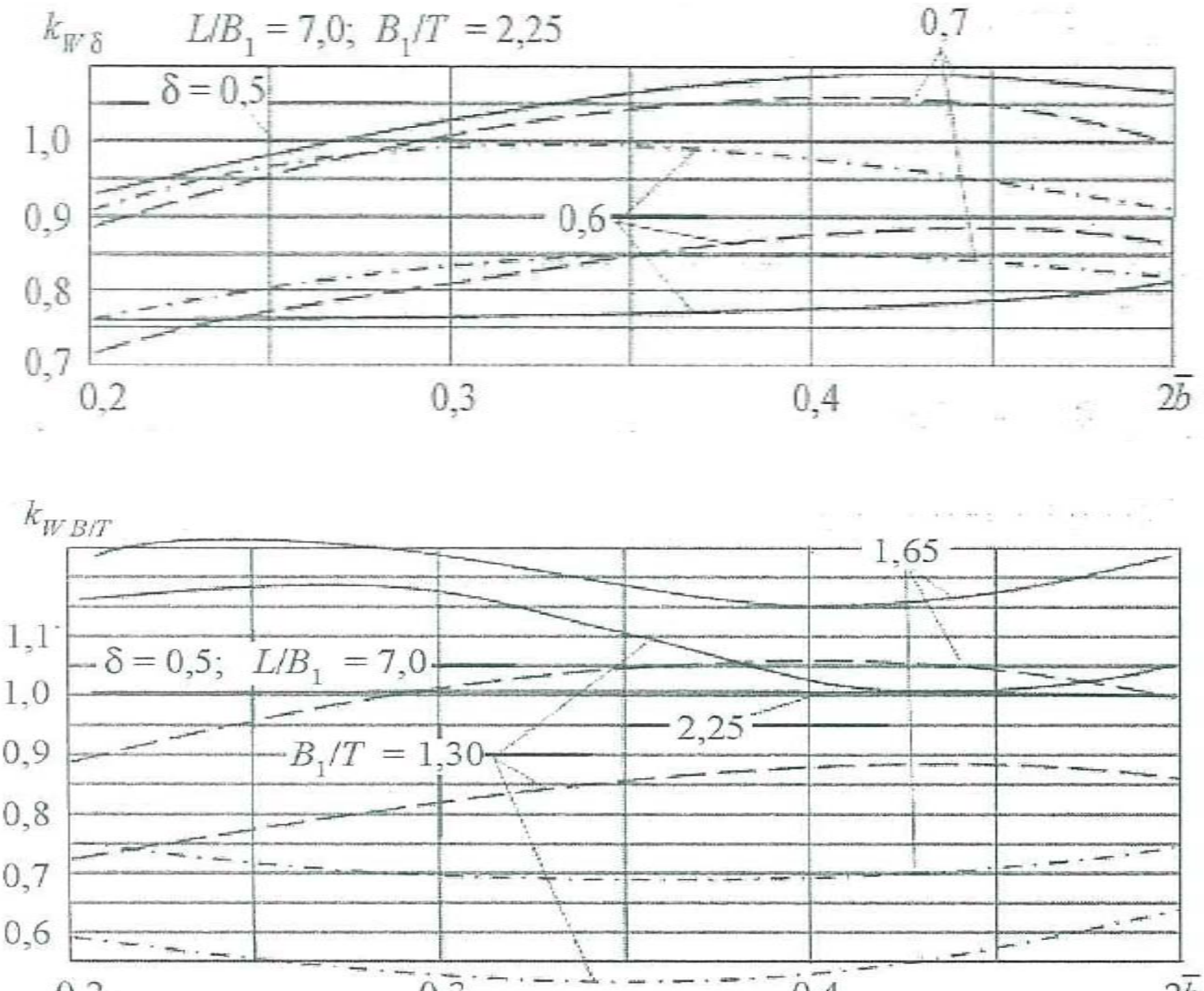


Figure 4.7. The impact coefficients of the wave resistance depending on the relative diametric clearance $2\bar{b}$, the relative length ***L/B₁*** , the block coefficient ***δ*** and the relative width ***B₁/T*** (Ref. - **Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007**).

$- - - - - l_1 = 6,0;$ ——— $- 7,0;$ –·–·–·– $- 8,0$

Example of calculation of catamaran's resistance with a cruiser stern.

Table 4.3. Input data to calculation example.

Input data:

Volumetric displacement, m^3:	
- total ***V***	930;
- one(single) hull V_1	465;
Speed υ_S, knots	11;
Speed υ_S, m/s	5,654;
Length on a waterplane (WL) ***L***, m	35,0;
Width, m:	
- total B_m	20,2;
- one (single) hull B_1	6,7;
Depth ***T***, m:	3,6;
Ratio:	
- L/B_1	5,22;
- B_1/T	1,86;
Block coefficient	δ = 0,550;
Prismatic coefficient	**φ = 0,633.**

Calculations of the subsidiary quantities.

The kinematic coefficient depending on the viscosity for the sea water ν (t =4°C) = 1.61 $\times 10^{-6}$ m^2/s.

The resistance coefficient of the hull form

$C_{VP} = R(Fr=0.2;\ l_1=5.22;\ \varphi = 0.633) = 0.35\times10^{-3}$ (see Figure 4.3).

The diametric clearance

$b=0.5\times(B_m-B_1)=0.5\times(20.2-6.7)$;

b=7.75 m.

The relative diametric clearance

$$2\bar{b}=2\frac{b}{L}=2\cdot\frac{7,75}{35,0};\quad 2\bar{b}=0,443.$$

The impact coefficients of the form resistance depending on the relative width B_1/T, the relative length L/B_1, the block coefficient δ and the relative clearance $2\bar{b}$:

$$k_{VP\,L/B} = k_{VP\,L/B}(L/B_1 = 5{,}22;\ 2\bar{b} = 0{,}443) = 1{,}50;$$

$$k_{VP\,B/T} = k_{VP\,B/T}(B_1/T = 1{,}86;\ 2\bar{b} = 0{,}443) = 0{,}97;$$

$$k_{VP\,\delta} = k_{VP\,\delta}(\delta = 0{,}550;\ 2\bar{b} = 0{,}443) = 0{,}97.$$

Assume: variation of C_F depending on the roughness and the extension of the hull

$\Delta C_F = 0.5\times10^{-3}$.

The wetted surface of the single hull

$$\Omega_l = \frac{\Omega_1}{V_1^{2/3}} V_1^{2/3}$$

where

$$\frac{\Omega_1}{V_1^{2/3}} = f\left(\frac{B_1}{T}; \frac{L}{B_1}; \delta\right) = f(1{,}86;\ 5{,}22;\ 0{,}550) = 5{,}75$$

(see Table 4.1)

$\Omega_1 = 5.75\times465^{2/3} = 5.75\times60$;

$\Omega_1 = 345\ m^2$.

The coefficient $\Omega_1 \times \rho = 1.025\times345 = 354$,

where ρ - is a density of sea water, $\rho = 1{,}025\ kg/m^3$.

The further calculations are made in a matrix form and shown in Table 4.4.

A speed range υ_S = (8...12, 15) knots will be used.

Table 4.4. Calculation of the resistance to a catamaran motion in a still water.

Item and size	**Numerical value**					
Speed υ_S, knots	8	9	10	11	12	15
Speed, m/s	4,112	4,626	5,140	5,654	6,168	7,72
Froude number $Fr = \frac{\upsilon}{\sqrt{gL}} = 0{,}054\upsilon$	0,222	0,250	0,278	0,305	0,333	0,417
Reynolds number $Re = \frac{\upsilon L}{\nu} = \frac{\upsilon 35}{1{,}61 \cdot 10^{-6}} = 2{,}17 \cdot 10^7 \upsilon$	$8{,}92 \cdot 10^7$	$10{,}04 \cdot 10^7$	$11{,}15 \cdot 10^7$	$12{,}27 \cdot 10^7$	$13{,}38 \cdot 10^7$	$16{,}78 \cdot 10^7$
The coefficient of friction resistance $C_F = \frac{0{,}455}{(\lg Re)^{2{,}58}}$ (see Table 4.2).	$2{,}16 \cdot 10^{-3}$	$2{,}13 \cdot 10^{-3}$	$2{,}10 \cdot 10^{-3}$	$2{,}07 \cdot 10^{-3}$	$2{,}04 \cdot 10^{-3}$	$1{,}98 \cdot 10^{-3}$
The coefficient of the form resistance of the single hull as a part of a catamaran $C_{VP}k_{VP}$ = $= k_{VP\ L/B} \times k_{VP\ B/T} \times k_{VP\ \delta} \times C_{VP} =$ $= 1{,}50 \times 0{,}97 \times 0{,}97 \times$ $\times 0{,}35 \times 10^{-3}$	$0{,}5 \cdot 10^{-3}$	$0{,}5 \cdot 10^{-3}$	$0{,}5 \cdot 10^{-3}$	$0{,}5 \cdot 10^{-3}$	$0{,}5 \cdot 10^{-3}$	$0{,}5 \cdot 10^{-3}$
The coefficient of the residual resistance of the hull C_R = C_R (Fr; l_1; φ) = C_R (Fr; 5,22; 0,633) (see Figure 4.3)	$0{,}7 \cdot 10^{-3}$	$0{,}8 \cdot 10^{-3}$	$1{,}2 \cdot 10^{-3}$	$1{,}7 \cdot 10^{-3}$	$2{,}7 \cdot 10^{-3}$	$4{,}3 \cdot 10^{-3}$
The wave drag coefficient of the hull $C_W = C_R - C_{VP} = C_R - 0{,}35 \times 10^{-3}$	$0{,}2 \cdot 10^{-3}$	$0{,}3 \cdot 10^{-3}$	$0{,}7 \cdot 10^{-3}$	$1{,}2 \cdot 10^{-3}$	$2{,}2 \cdot 10^{-3}$	$3{,}95 \cdot 10^{-3}$

The impact coefficient of the wave resistance depending on the relative length ***L/B₁*** → see below						

The impact coefficient of the wave resistance depending on the relative length $\boldsymbol{L/B_1}$, the diametric clearance $2\bar{b}$ and the Froude number $\boldsymbol{Fr}$: $k_{W\ L/B} = k_{W\ L/B}\left(\frac{L}{B_1}; 2b; \mathrm{Fr}\right) = k_{W\ L/B}(5{,}22;\ 0{,}443;\ \mathrm{Fr})$ (see Figures 4.6 and 4.7)	1,00	1,40	1,50	1,50	1,50	1,50
The impact coefficient of the wave resistance depending on the block coefficient $\boldsymbol{\delta}$, the diametric clearance $2\bar{b}$ and the Froude number $\boldsymbol{Fr}$ **:** $\boldsymbol{k_{W\ \delta}} = k_{W\ \delta}(\ \delta;\ 2b;\ Fr) = k_{W\ \delta}(0{,}550;\ 0{,}443;\ Fr)$-(see Figure 4.6 and 4.7)	0,90	0,90	0,90	0,90	0,90	0,90
The impact coefficient of the wave resistance depending on the relative width $\boldsymbol{B_1/T}$, the diametric clearance $2\bar{b}$ and the Froude number $\boldsymbol{Fr}$: $k_{W\ B/T} = k_{W\ B/T}\left(\frac{B_1}{T}; 2b; \mathrm{Fr}\right) = k_{W\ B/T}(1{,}86;\ 0{,}443;\ \mathrm{Fr})$ (see Figure 4.6 and 4.7)	0,95	0,95	0,95	1,10	1,10	1,10
The wave drag coefficient of the single hull as a part of catamaran $\boldsymbol{k_W C_W} = C_W \times k_{W\ L/B} \times k_{W\ \delta} \times k_{W\ L/B} = = C_W \times k_{W\ L/B} \times k_{W\ \delta} \times k_{W\ B/T}$	$0{,}17 \cdot 10^{-3}$	$0{,}36 \cdot 10^{-3}$	$0{,}90 \cdot 10^{-3}$	$1{,}78 \cdot 10^{-3}$	$3{,}27 \cdot 10^{-3}$	$5{,}64 \cdot 10^{-3}$
The drag coefficient of the single hull as a part of catamaran $\boldsymbol{C_K} = C_F + k_{VP}C_{VP} + k_W C_W + \Delta C_F = C_F + C_{VP}k_{VP} + k_W C_W + 0{,}5 \cdot 10^{-3}$	$3{,}54 \cdot 10^{-3}$	$3{,}70 \cdot 10^{-3}$	$4{,}21 \cdot 10^{-3}$	$5{,}06 \cdot 10^{-3}$	$6{,}52 \cdot 10^{-3}$	$8{,}62 \cdot 10^{-3}$

$\upsilon^2 = \upsilon^2$, m/s^2	16,91	21,40	26,42	31,97	38,04	59,6
The towing resistance of a catamaran $\boldsymbol{R} = 2C_K \times \rho\upsilon^2/2 \times \Omega_1 = 354 \times C_K \times \upsilon^2$, kN	42,4	56,0	78,8	114,4	175,6	363,7
The tow-rope power $\boldsymbol{P_E} = R\upsilon = R \times \upsilon$, kW	174,4	259,0	405,0	646,8	1083,2	2808,1

The results of the calculation are shown on Figures 4.8.*a* and 4.8.*b* *).

***)** - For the approximate evaluation of the towing resistance and the power of a catamaran the block coefficient δ and the relative width $\boldsymbol{B_1/T}$ can be neglected. Therefore, it normally can be considered that the following coefficients $k_{VP\ B/T} \times k_{VP\ \delta} \times k_{W\ B/T} \times k_{W\ \delta}$ all are equal to **1**:

$$k_{VP\ B/T} \times k_{VP\ \delta} \times k_{W\ B/T} \times k_{W\ \delta} = 1$$

Towing resistance $\boldsymbol{R}$, (kN)	42,4	56,0	78,8	114,4	175,6	363,7
Tow-rope power $\boldsymbol{P_E}$, (kW)	174,4	259,0	405,0	646,8	1083,2	2808,1
Speed υ_S,(knots)	8	9	10	11	12	15

Table 4.5. Speed υ_S of the given catamaran depending on the towing resistance $\boldsymbol{R}$ and on the tow-rope power $\boldsymbol{P_E}$.

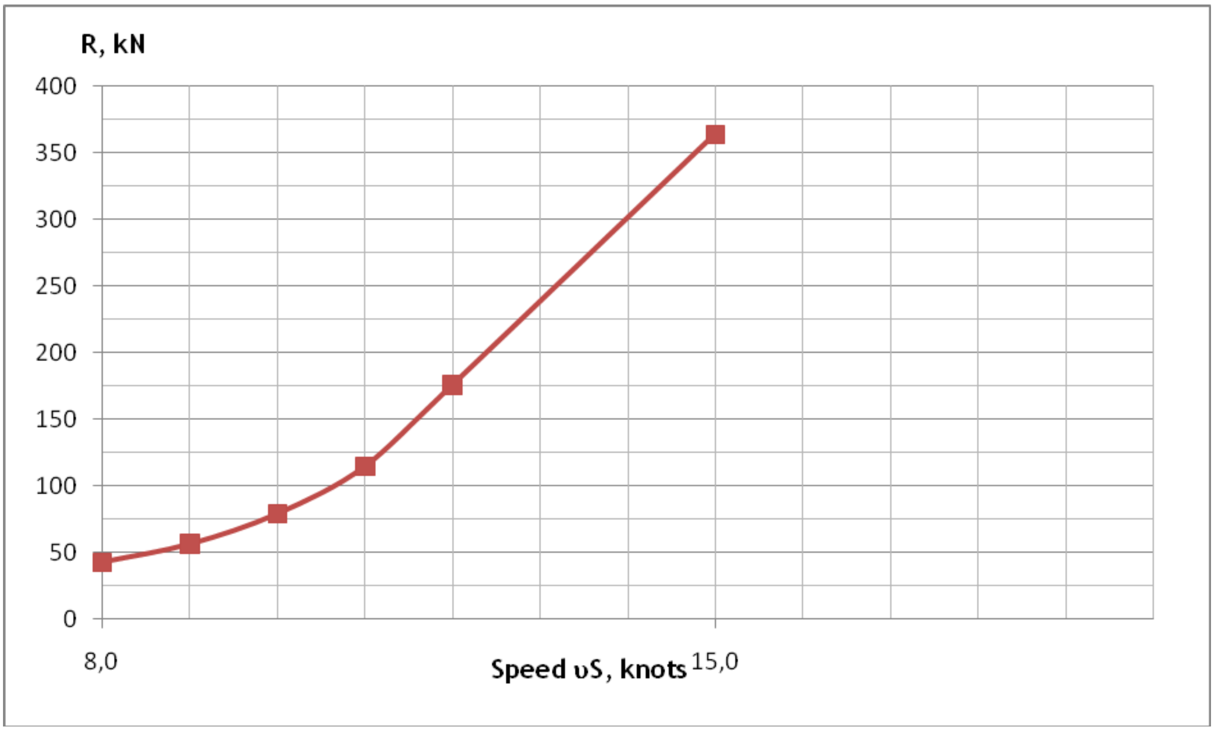


Figure 4.8.*a*. The curve of the towing resistance ***R*** of the given catamaran.
(Ref. - Сликевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).

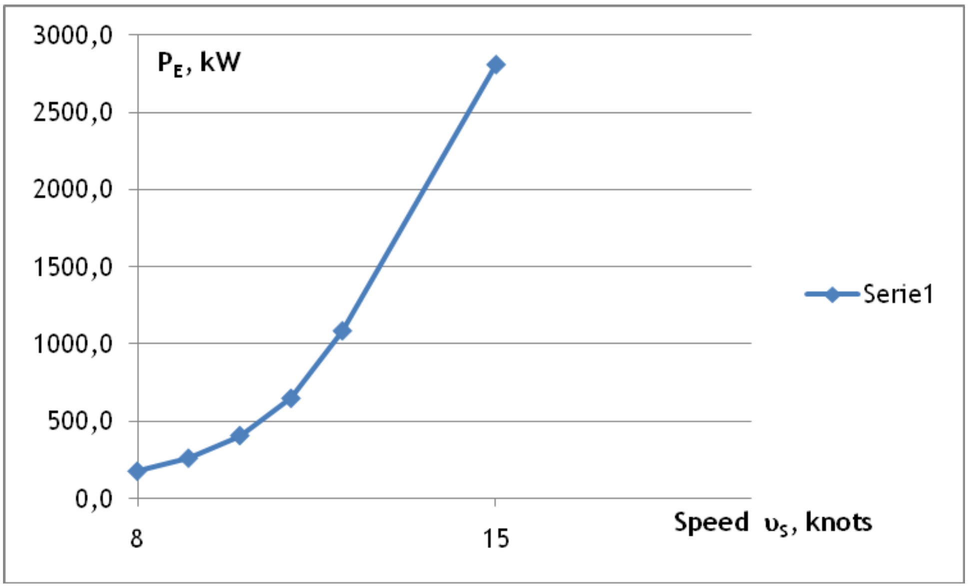


Figure 4.8.*b*. The curve of the tow-rope power P_E of the given catamaran.
(Ref. - Сликевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).

CONCLUSION: *For the given example with certain given parameters the Froude number should not exceed 1 (hence, as much as possible the chosen speed should not exceed approximately 30 knots), because the given vessel in this case should respond as a high speed boat(a skimmer craft),it means that the vessel will glide (slide) on the water surface. Or, to receive a higher speed, other initial parameters should be given at the beginning of the calculation. The example of a skimmer craft (a high speed vessel) will be considered in a further Chapter (A trimaran vessel will be used as an example).*

Resistance of a trimaran.

The three-hull vessel consists of the central hull, which is placed more to the front and 2 incorporated hulls united with the central hull. It allows us to combine the advantages of a monohull with the advantages of catamarans in the deck area, the amplitude of the roll will be minimized and the high transverse stability will increase. (see Figure 4.9).

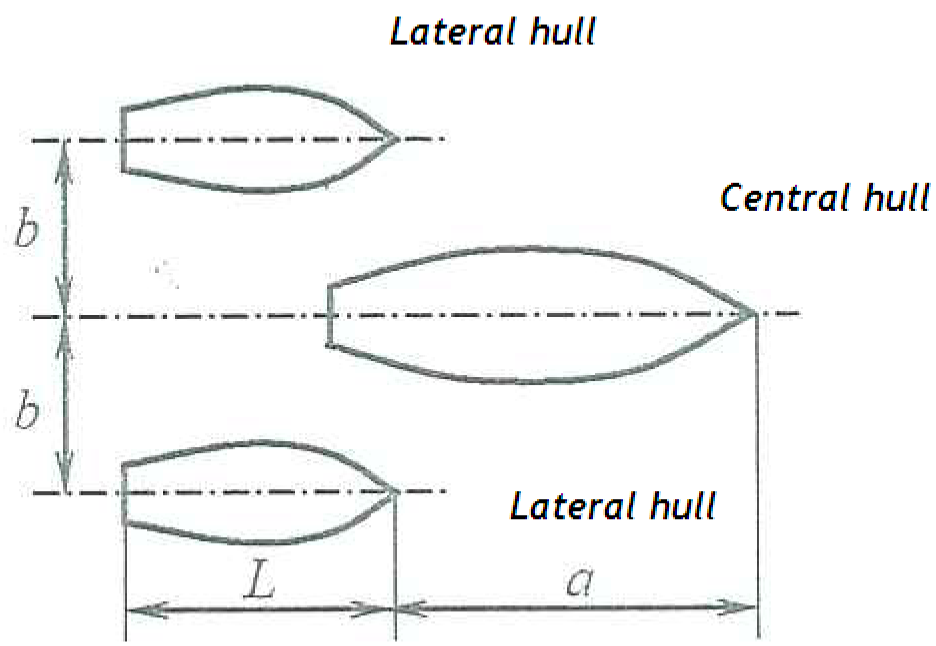


Figure 4.9. The scheme of the hulls arrangement of a trimaran.
(Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).

The main advantages of trimarans:

- The concentration of the largest part of the displacement in the central hull allows us to reduce the specific wetted surface of the vessel in comparison with a catamaran;
- The longitudinal shift of the lateral hulls to the stern side has an effective impact on the wave resistance;
- As a result of the waves impact on the central (main) hull, the effect of an impact of these waves into the connection between the hulls decreases;
- For catamarans, there is an opportunity to create a greater deck area; possibilities to design a more convenient general arrangement drawing.

The resistance to movement in water of a trimaran, as for a catamaran, can be defined as the sum of the following resistances:

$$R = R_F + R_{VP} + R_W + \Delta R,$$

where

R_F ,R_{VP}, R_W - are the total resistance of the friction, the form and the wave resistance of three hulls of a trimaran;

ΔR - is the total increase of the resistance depending on the extension (prominent part of a trimaran hull), the roughness and the air.

Furthermore, the total drag coefficient of a trimaran will be:

$$C = C_F + C_{VP} + C_W + \Delta C.$$

The impact of the central hull and of the lateral hulls into a total resistance is different, because of the hydrodynamical effect, which can be defined by the relative positioning of hulls and their characteristics and by the speed of the motion.

Since the number of the parameters defining the resistance of a trimaran, is great, there are no practical methods of calculations of this resistance nowadays, which are based on the results of regular modelling experiments.

As a result of the theoretical and experimental research on the impact of separate geometrical parameters of the relative positioning of the hulls (depending on the resistance) the following conclusions were made (Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007):

- the range (the change) of the transverse clearance ***b*** (is the distance between the centreline ***CL*** (see Figure 4.2) of the central and lateral hulls), within admissible limits does not show an essential impact on the wave resistance;
- the longitudinal shift of the hulls makes the greatest (positive) impact on the wave resistance;
- information about the impact of the hydrodynamical interaction (depending on the friction resistance of the hulls for existing numbers of the transverse clearance b and the shift a) is practically about calculations of the friction resistance of the hulls of a trimaran as a summation of the friction resistance of the isolated hulls;
- on the form resistance of a trimaran the transverse clearance and the shift are making a bigger impact compared with an impact of the Froude number, which can be neglected.

The shown experiments and research allow us to develop a sufficient background for calculations of the resistance of a trimaran motions with identical hulls. In this case the total drag coefficient of a trimaran depending on the wetted surface of the single hull will be:

$$C = 3C_F + 3k_{VP} \cdot C_{VP} + (3C_W + \Delta C_W) + \Delta C_1,$$

where

C_F = $C_F(Re)$ - is the friction coefficient of the isolated hull of a catamaran, taken according to the formula of Prandtl-Shlihtyng *) ;

*) - the value can be calculated by using a Table 4.1.

$$C_F = \frac{0,455}{(\lg \mathrm{Re})^{2,58}}$$

C_{VP} - is the form drag coefficient of the isolated hull, which can be defined approximately by using the Figures 4.2 and 4.3, and has to be equate with the residual resistance coefficient at

$$\mathrm{Fr} = 0,2;\ C_{VP} = C_R\left(\mathrm{Fr} = 0,2;\ l_1 = \frac{L}{B_1};\ \varphi\right);\ k_{VP} = k_{VP}\left(\bar{b} = \frac{b}{L};\ \bar{a} = \frac{a}{L}\right)$$

K_{VP} - is the corrective coefficient depending on the transverse clearance and the shift. This coefficient can be calculated by using Figure 4.10.

$C_W = C_R(Fr;\ l_1;\ \varphi)C_{VP}$ - the wave resistance coefficient of the single hull, can be taken from the Figures 4.2 and 4.3.;

$\Delta C_W = \Delta C_W(\acute{\alpha};\ Fr)$ - the changes of the wave resistance coefficient of a trimaran are calculated by using Figure 4.11 (I and II);

ΔC_1 - the increase of the resistance of a trimaran depending on the impact of the roughness, the extension parts and the air resistance of the single hulls. It is equal to the increase of the resistance of monohulls.

But if we will assume that 2 lateral hulls are identical to each other, and the central hull is bigger than the lateral hulls, in this case, the total drag coefficient of a trimaran depending on the wetted surface of the single hull will be:

$$C = [2C_{F\,LH} + 2k_{VP} \cdot C_{VP\,LH} + (2C_{W\,LH} + \Delta C_W) + \Delta C_1] + [C_{F\,CH} + k_{VP} \cdot C_{VP\,CH} + (C_{W\,CH} + \Delta C_W) + \Delta C_1],$$

where

$C_{F\,LH} = C_F(\mathrm{Re})$ - is the friction coefficient of the isolated lateral hull of a catamaran, taken according to the formula of Prandtl-Shlihtyng *) ;	$C_{F\,CH} = C_F(\mathrm{Re})$ - is the friction coefficient of the isolated central hull of a catamaran, taken according to the formula of Prandtl-Shlihtyng *) ;
*) - the value can be calculated by using a Table 4.1. $C_F = \frac{0,455}{(\lg \mathrm{Re})^{2,58}}$	
$C_{VP\,LH}$ - is the form drag coefficient of the isolated lateral hull, which can be defined approximately by using the Figures 4.2 and	$C_{VP\,CH}$ - is the form drag coefficient of the isolated central hull, which can be defined approximately by using the Figures 4.2 and

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<tr><td colspan="2">K_{VP} - is the corrective coefficient depending on the transverse clearance and the shift. This coefficient can be calculated by using Figure 4.10.</td></tr>
<tr><td>$C_{W\ LH} = C_R\ (Fr;\ l_1;\varphi) \cdot C_{VP}$ - the wave resistance coefficient of the single lateral hull, can be taken from the Figures 4.2 and 4.3.</td><td>$C_{W\ CH} = C_R\ (Fr;\ l_1;\varphi) \cdot C_{VP}$ - the wave resistance coefficient of the single central hull, can be taken from the Figures 4.2 and 4.3.</td></tr>
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<tr><td colspan="2">ΔC_1 - the increase of the resistance of a trimaran depending on the impact of the roughness, the extension parts and the air resistance of the single hulls. It is equal to the increase of the resistance of monohulls.</td></tr>
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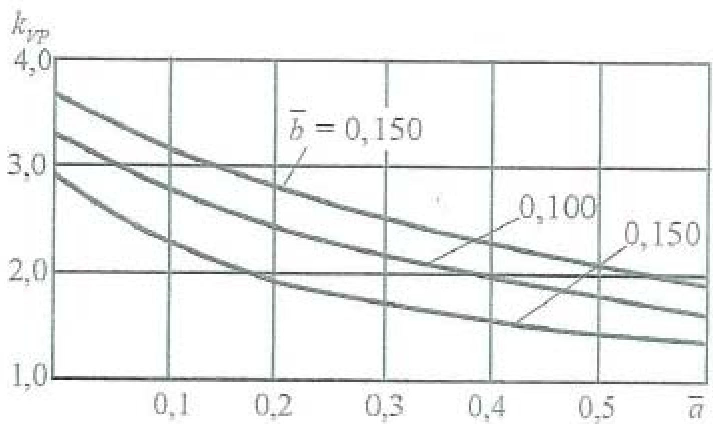
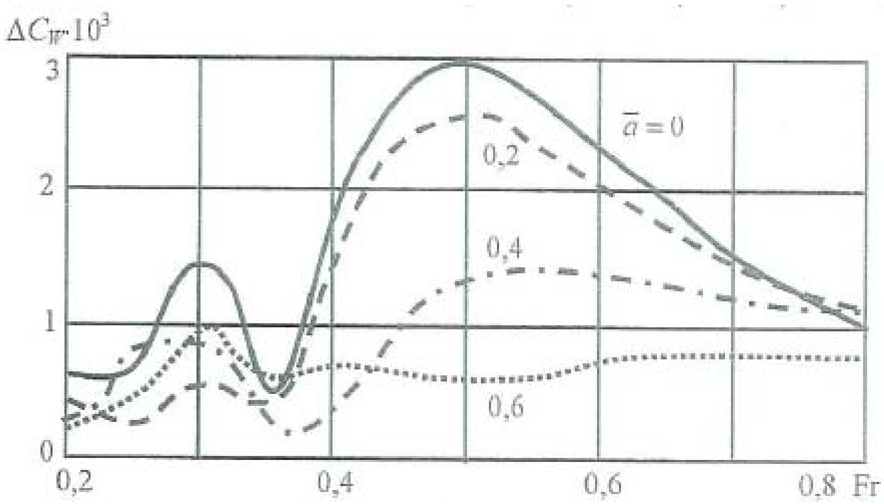
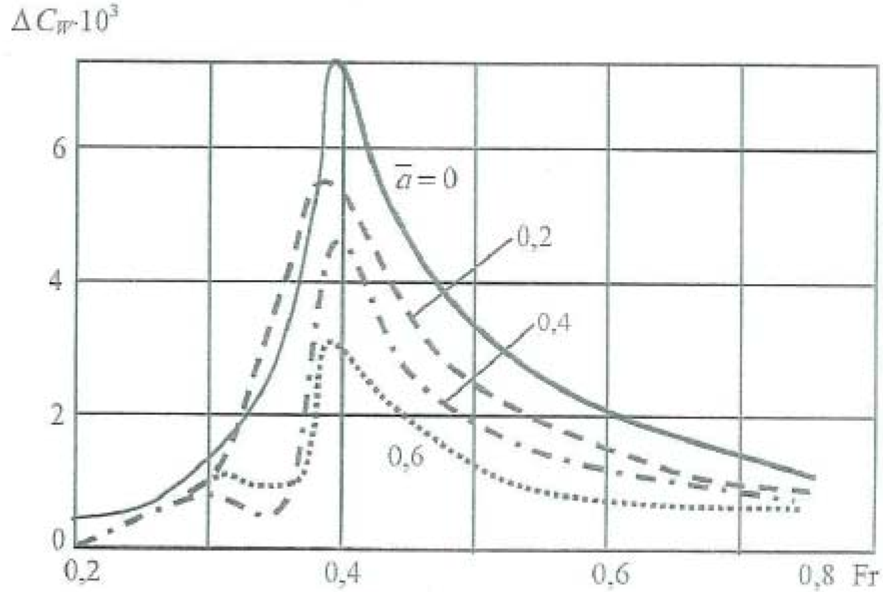


Figure 4.10. Graph shows the relation between coefficient k_{VP} and relative numbers of the relative shift $\bar{a}$ and the relative transverse clearance $\bar{b}$.

(Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).



I.



II.

Figure 4.11. Graph shows the relation between coefficient ΔC_W of a trimaran in a deep **(**I**)** and in shallow water **(**II**)** and the Froude number ***Fr*** and the relative shift $\bar{a}$.

(Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).

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CHAPTER 5:

RESISTANCE OF A HIGH-SPEED CATAMARAN (A SKIMMER CRAFT).

The glide mode represents a sliding of the vessel on the water surface and the vessel gains a high speed at the same time. The Froude number is:

$$Fr_V = \frac{\upsilon}{\sqrt{g\sqrt[3]{V}}} > 3,$$

where υ - is the speed, m/s; V – displacement in the navigation mode, m^3.

The bottom of a speedboat is a bearing surface. The lifting force occurs when the speedboat's bottom slides on the surface with some angle. This lifting force balances the weight of the vessel. Skimmer crafts are build more than 100 years and they are widely in use on river and sea fleets.

This type of vessels is used for different purposes. Their speeds on still water can reach about 50-60 knots (25.7 – 30.8 m/s). ***NOTE***: 1knot ≈ 0.514 m/s ≈ 1.85 km/h.

In this Chapter we will discuss more about high-speed catamaran.

The main disadvantage of these vessels is the low seaworthiness that limits their dimensions and makes inconvenient the use of the high-speeds in open waters with strong winds and big waves.

Typical high-speed vessels in a glide mode are moving with a small trim angle (1° to 2°). This significantly reduces the support ability of a speedboat (see Figure 5.1). An effort to increase the trim angle (to 4°, to 5°) by displacement of the centre of gravity to the stern leads to decreases in the stability.

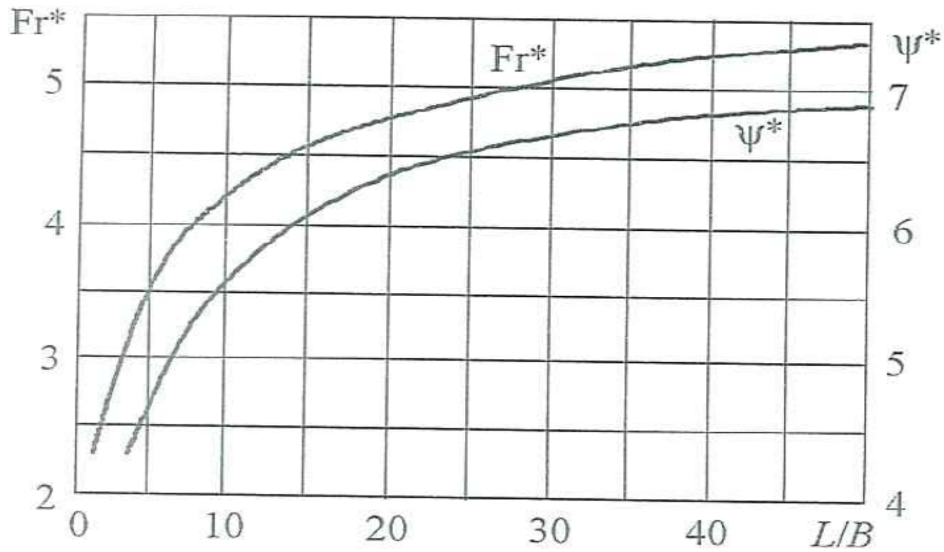


Figure 5.1. The impact of the lengthening ***L/B*** of a high-speed vessel on the Froude number ***Fr**** and on the corresponding trim angle ψ^*, which define the transition of the vessel into a glide mode $\bar{a}$. (Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).

By using a catamaran scheme the weight of the vessel is distributed between two bearing surfaces, the lengthening of each is increasing more than the lengthening of an equal high-speed monohull.

According to the graphs in Figure 5.1 the trim value is increasing up to an optimum value that finally leads to growth of the bearing ability of the hull of the catamaran in comparison with an equal high-speed monohull.

Even by having a number of operational advantages, such as: good cross-section stability, a big deck area and so on, the catamaran scheme of a high-speed vessel has some disadvantages. One of them is the necessity of a higher speed to achieve a glide mode in comparison with monohulls.

Theoretical and experimental tests are carried out to establish the following parameters which define the glide quality of catamarans:

- ***the transverse clearance*** ***b***, the value is characterized by the ratio $2B_1/B_m$, where

$2B_1$ - is the total width of the hulls, B_m - the total width of the catamaran. By reducing the transverse clearance B_m and with growth of the $2B_1/B_m$ ratio respectively, the catamaran will proceed into a glide mode (where the resistance R is independent of the speed Fr) later (see Figure 5.2). Two "peaks" of the resistance, are observed:

- at $Fr < 4$ the first "peak" is formed, which will disappear when the speed of the vessel's motions will be increasing;
- the second "peak" of the resistance will be observed at a speed $Fr=5$, independently of the value of the transverse clearance. (Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).

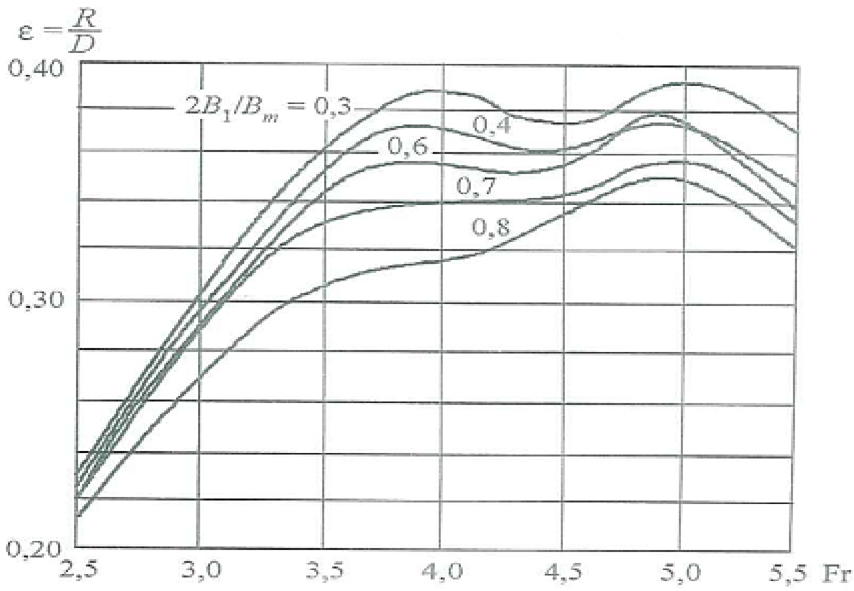
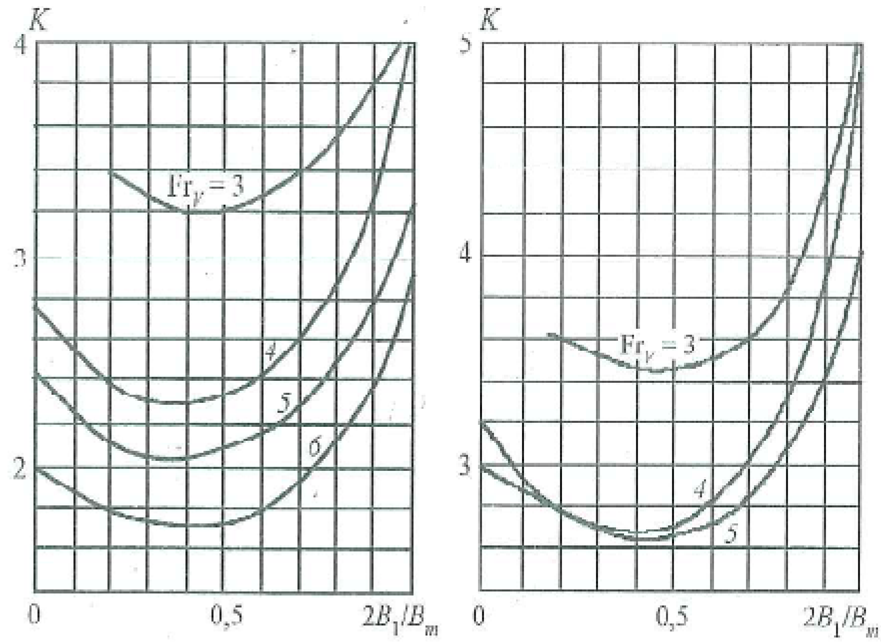


Figure 5.2. Curves of the resistance of a high-speed catamaran with a various values of the transverse clearance (***D*** is teh weight of the catamaran $\varepsilon = R/D$).

(Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).

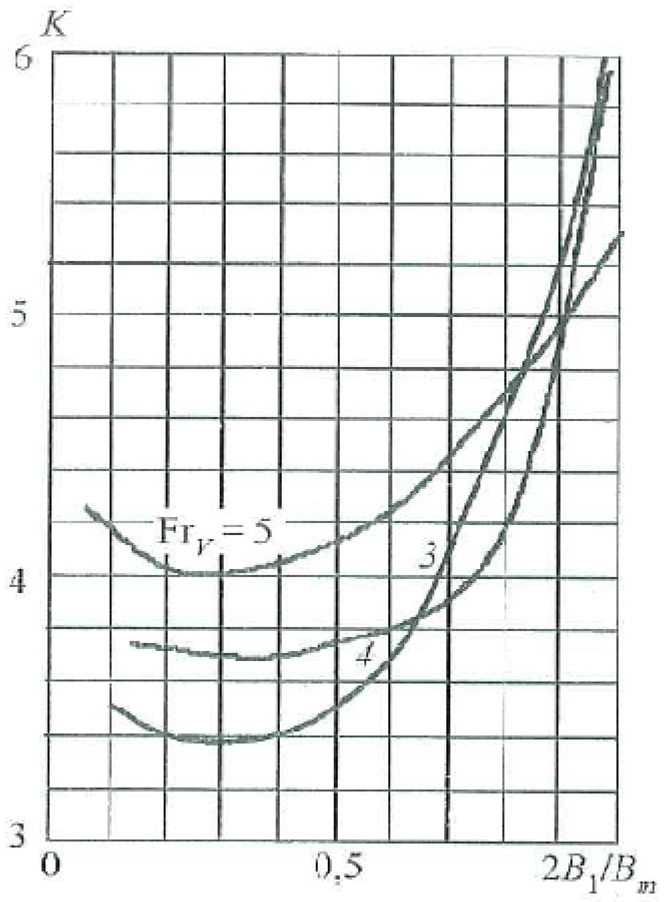
The ratio $2B_1/B_m \approx 0.4$ is the "worse" ratio from the side of the value of the resistance of the high-speed vessel's motion. In this case (see Figure 5.3) the ***glide quality*** of the catamaran ***K*** - is the ratio of the weight to the resistance. The smallest one meaning that the resistance is highest for this value.

- when ***the ratio*** L/B_1 decreases,then the resistance of the motion decreases;
- ***the relative speed*** Fr_V (***the Froude number Fr***), does not make an essential impact on the ratio of the high-speed catamaran's hydrodynamic quality;
- ***the form of the hull of the high-speed catamaran*** makes an appreciable impact on the resistance of the vessel.



a ***b***

Legend: see next page.



c

Figure 5.3. The impact of the relative distance between hulls on the hydrodynamical quality ***K*** for different values of ***C_V*** of a high-speed catamaran:

$$a - C_V = \frac{V}{(2B_1)^3} = 0{,}386 \quad b - 0.578;\ c - 0.943$$

(Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).

The experimental graphs allows us to calculate the resistance of the high-speed catamaran as:

$$R = D/K,$$

where ***D*** – is the weight of a catamaran, measured in N or kN; ***K*** - is the hydrodynamical quality of the high-speed catamaran;

K = D/R can be defined by using the graphs in Figure 5.2; $K = K\cdot(L/B_1;\ C_V;\ Fr_V);$

$C_V = V/\ (2B_1)^3$ - is the coefficient of the static load ;

$Fr_V = \upsilon / \sqrt{gV^{1/3}}$ - is the Froude number depending on the displacement of the catamaran; ***V*** – is the displacement of the two hulls of the catamaran, m^3;

By using the graphs for ***K*** (see Figures 5.3 and 5.4) it is possible to solve yhe inverse problem and find the resistance for a given displacement ***V***, speed υ , ratio ***L/B₁*** and transverse clearance (which is given by the ration $2B_1/B_m$).

NOTE: We use <u>either</u> Figure 5.3 or Figure 5.4 to find ***K.***

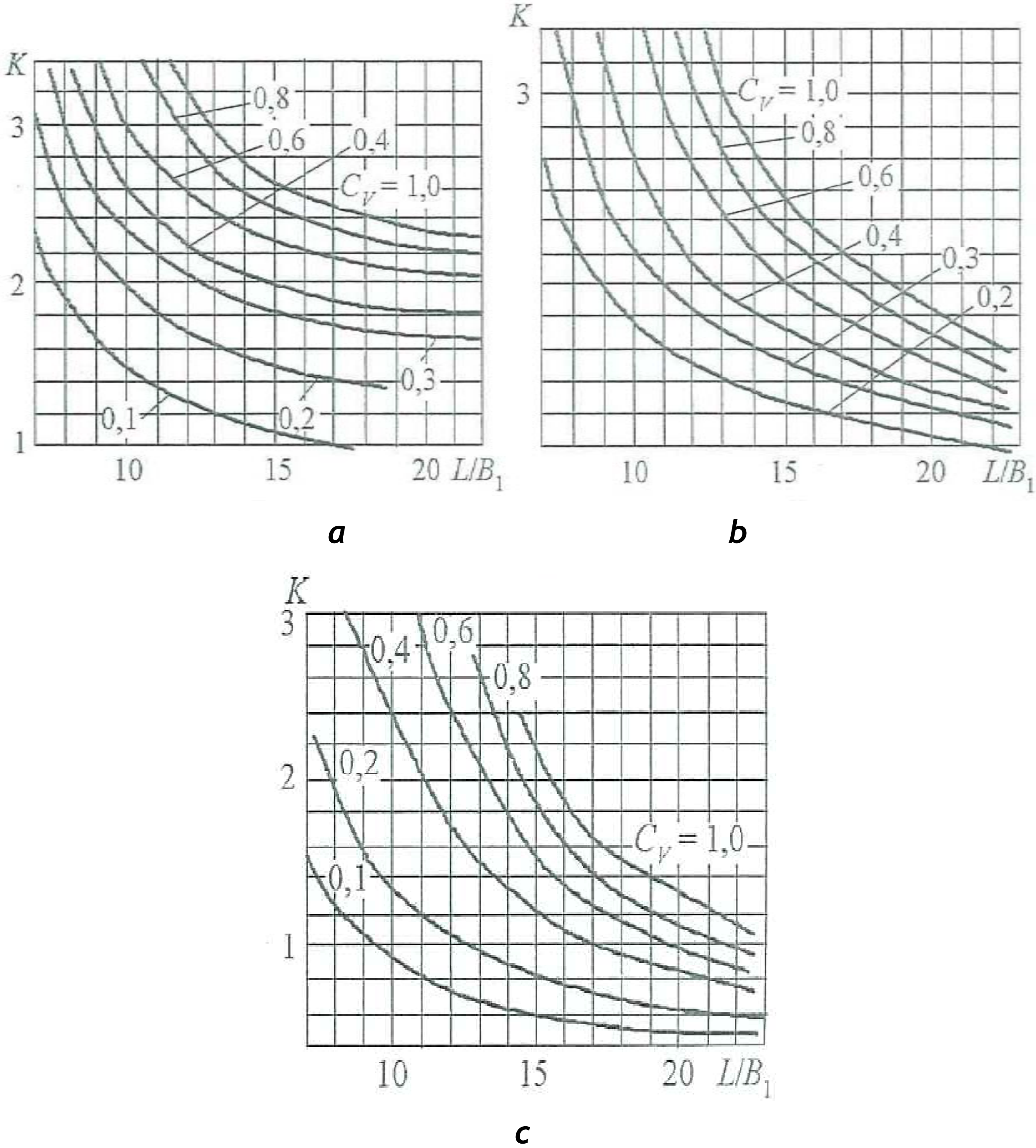


Figure 5.4. The hydrodynamical quality ***K*** of a high-speed catamaran depending on the lengthening of the hulls L/B_1, the relative speed Fr_V and the coefficient C_V:

a - Fr_V =4.0;   ***b*** - Fr_V =5.0;   ***c*** - Fr_V = 6.0.

(Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).

CHAPTER 6:

CALCULATION OF THE MAIN ENGINES CAPACITY OF A MULTIHULLS (ON AN EXAMPLE OF A CATAMARAN).

As SPU (ship's power unit) on catamarans the forced high circulation explosion engine with a reduction gear (reducer) is more common in use. Often an SPU is connected to power take-off shafts, located in both hulls symmetrically.

Drill installations, research vessels and FPSOs are equipped with special (according to the purpose of these vessel) mechanisms and equipments with a big capacity. Therefore, diesel electric engines with independent are mainly in use.

Preliminary calculations of the main elements and type of screw propellers.

For long offshore trips, the unstable motions and harsh weather conditions in the North Sea the use of screw propellers:

- free fixed pitch propellers (FPP) or free controllable pitch propeller (CPP);
- screw propellers FPP or CPP in a nozzle.

Controllable pitch propellers (CPP) for marine propulsion systems have been designed to give the highest propulsive efficiency for any speed and load condition. When the vessel is fully loaded with cargo the propulsion required at a given ship speed is much higher than when the vessel is empty. By adjusting the blade pitch, the optimum efficiency can be obtained and fuel can be saved. (Ref. **- http://en.wikipedia.org/wiki/Controllable_pitch_propeller)**

The main features of the *controllable pitch propeller* design are (see Figures 6.1 and 6.2):

- Highest propulsive efficiency in all operating conditions;
- Excellent behaviour regarding cavitation, with no erosive types of cavitation;
- Lowest pressure pulse fluctuations on the hull to minimize noise and vibration levels on board.

(Ref. - **http://www.wartsila.com/Wartsila/norway/docs/locals/norway/Products_and_services/Propellers.pdf)**

a *b*

C *d*

Figure 6.1. The vessel examples with controllable pitch propellers (CPP):

a **-** Tanker Credo**;** ***b*** **-** Twin-screw offshore supply ship Normand Ivan;

c **-** Seismic reseach vessel Ramford Souverign; ***d*** – Twin-screw hopper dredger Rotterdam.

(Ref. - **http://www.wartsila.com/Wartsila/norway/docs/locals/norway/Products_and_services /Propellers.pdf)**

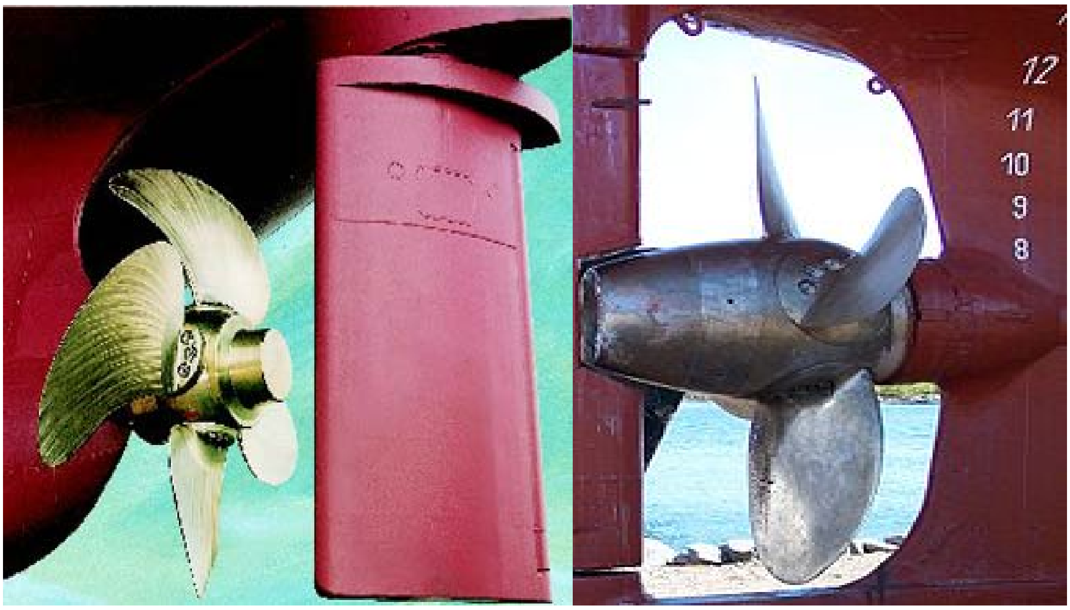


Figure 6.2. An example of a ship with controllable pitch propeller (CPP).
(Ref. - **http://en.wikipedia.org/wiki/Controllable_pitch_propeller**)

In order to achieve the highest possible total efficiency of the vessel, the propeller must be a perfect match with the engine and the hull. ***A fixed pitch propeller (FPP)*** is the choice when optimum efficiency, reliability and robustness are required (See Figures 6.3 and 6.4). FPP propellers are usually applied in ocean sailing vessels, for example container vessels, tankers, bulk carriers and dry cargo vessels. (Ref. **- http://www.wartsila.com/).**

Figure 6.3. An example of a ship with fixed pitch propeller (FPP).
(Ref. - **http://www.wartsila.com/).**

Figure 6.4. The engine is linked to a fixed pitch skew propeller (FPP). (Ref. - **http://www.ship-technology.com/projects/manukai_maunawili/images/image5.jpg&imgrefurl)**

A fixed pitch propeller (FPP) can be more efficient than a controllable pitch propeller, however it can only be so at one rotational speed and the designed load condition. At that one rotational speed and load, it is able to absorb all the power that the engine can produce. At any other rotational speed, or any other vessel loading, the FPP cannot, either being over pitched or under pitched. A correctly sized controllable pitch propeller can be efficient for a wide range of rotational speeds, since the pitch can be adjusted to absorb all the power that the engine is capable of producing at nearly any rotational speed.

The CPP also improves the maneuverability of a vessel. When maneuvering the vessel the advantage of the CPP is the fast change of propulsion direction. The direction of thrust can be changed without slowing down the propeller and depending on the size of the CPP the directioncan be changed in approximately 15 to 40 seconds. The increased maneuverability can eliminate the need for docking tugs while berthing.

A reversing gear or a reversible engine is not necessary anymore, saving money to install and service these components. Depending on the main engine rotational speed and the size of the CPP, a reduction gear may still be required. A CPP does require a hydraulic system to control the position of the blades. A CPP does not produce more or less wear or stress on the propeller shaft or propulsion engine than an FPP. Therefore maintenance will not be an argument to choose between an FPP or a CPP.

Most ships that wouldn't take a CPP are large vessels that make long trips at a constant service speed, for example crude oil tankers or the largest container ships which have so much power that a CPP is not yet designed for them. A CPP can mostly be found on harbour or ocean-going tugs, dredgers, cruise ships, ferries, cargo vessels and larger fishing vessels that sail to ports with limited or no tug assistance. (Ref. - **http://en.wikipedia.org/wiki/Controllable_pitch_propeller).**

CPP and FPP can be running in a nozzle (see Figure 6.5). The advantage of using nozzles comes from the additional amount of thrust this develops.

Nozzles or ducted propellers are propellers surrounded with a hydro dynamically shaped ring or shroud. The shroud fits very closely around the propeller blade tips and is specifically designed to accelerate water flow through the propeller.

Ducted propellers offer significantly increased efficiency and increased thrust over standard open propellers, but only at low speeds, this makes them ideally suite to fishing vessels and tugs.

Ducted propellers where the propeller is placed in some form of duct work, have different operating characteristics than open propellers. This is primarily due to the fact that the duct acts so as to regulate the mass flow rate through the unit. The result is that the flow angles within the unit are very nearly independent of operating conditions and so ducted units characteristically have superior off design characteristics. In particular, their torque is dependent almost entirely upon RPM and almost independent of ship speed. If they are matched well with the engine at the operating condition, then they are well matched at all conditions. The angles of attack at the inlet to the duct do depend upon operating conditions and has to be suitable designed according to the mission of the ship. (Ref. – **" Hull Form and Propulsor Technology for High Speed Sealift", revised: 13 February 1998. Edited by: CHRIS B. MCKESSON, PE**).

Figure 6.5. The pitch propeller in a nozzle.
(Ref. - **http://www.frenchmarine.com/marine_propeller_repair.aspx**)

In the example in Figure 6.5 the bollard pull or thrust was measured after the nozzle was fitted. By installing the nozzle the thrush developed had been increased by 28%.

The preliminary choice of the basic elements of a screw propeller (diameter D, number of blades Z, individual blade-area ratio A_E/A_0 (where A_E is the area of individual blade and A_0 is the area of the nozzle), the contour form and angle of the blades' inclination, diameter of the hub and other elements) can be made according to the following recommendations:

- Based on accommodating the screw propeller in the aft part of the vessel the maximum value of the diameter ***D*** of the screw propeller is chosen depending on the draught T_k of the vessel at the stern:

$$D = (0,68...0,75)\cdot T_k ;$$

- The number of the blades can be:

  Z = 3, if $K_{DE} \geq 2$;

  Z = 4, if $K_{DE} \leq 2$;

  where

$$K_{DE} = D\upsilon\sqrt{\rho / R_1}$$

K_{DE} - is the loading coefficient of the screw propeller depending on the power; is the resistance of a catamaran;

ρ - is the density;

υ - is speed;

R_1 – is towing resistance.

- The size of the blade-area ratio A_E/A_0 should be selected according to special formulas and diagrams and the shouldn't be any cavitations (this information should be taken from special directories, handbooks or guide-books);
- As the last, a screw propeller (see Figure 6.6) with a corresponding preliminary characteristics and screw diagram should be chosen; This as to be decided by using calculations, (free or in a nozzle the screw propeller).

(Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).

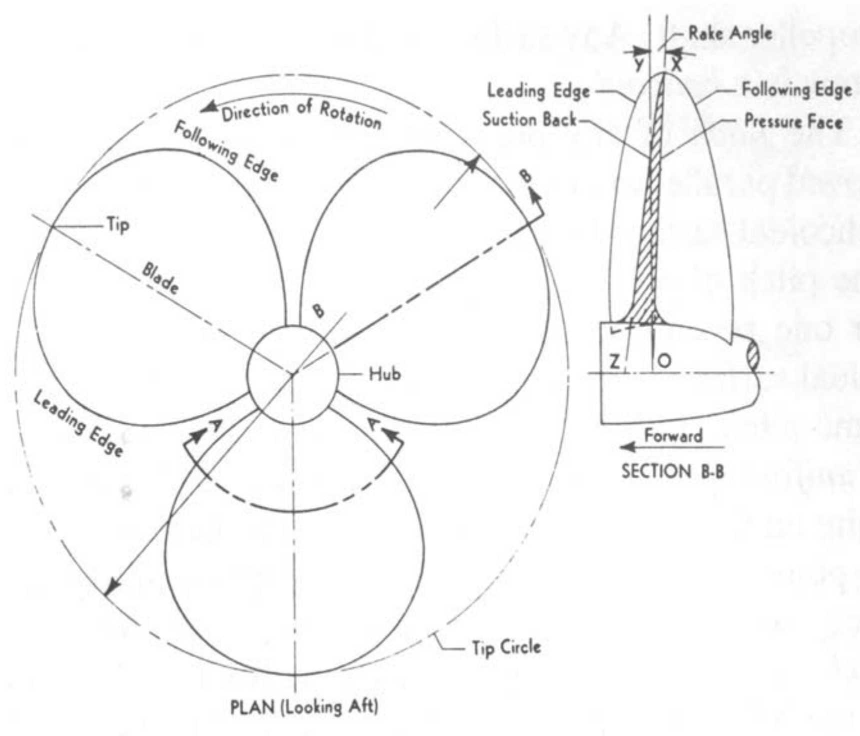


Figure 6.6. A screw propeller overview.

(Ref. - **http://en.wikipedia.org/wiki/Controllable_pitch_propeller**).

Calculation of the interaction coefficients of the screw propeller and the hulls of a catamaran.

It is necessary to say that a catamaran has 2 screw propellers; both of them are located in the stern of the hull. A trimaran has 2 screw propellers also, but they are located in a stern of the lateral hulls, one in the each lateral hull of a trimaran.

The interaction coefficients of the catamaran's hull with a screw propeller are connected with corresponding interaction coefficients of a monohull:

$$\omega_K = k_\upsilon \cdot \omega;\ t_k = k_t \cdot t;\ i_K = i_{s,}$$

where $\boldsymbol{\omega_K}$, $\boldsymbol{t_k}$, $\boldsymbol{i_K}$ – are the coefficients of the sucking water flow and of the impact of the double-hull depending on the hydrodynamical interaction of the hulls and the screw propellers of the two hulls of a catamaran;

***ω, t**, **i**$_s$* - are the coefficients of the sucking water flow and of the impact of the double-hull depending on the hydrodynamical interaction of the hulls and the screw propellers of the single hull (monohulls);

k_{υ}, k_t - the interaction coefficients of the hulls of a catamaran depending on the screw wake and on the sucking water flow.

The values of the coefficients of the screw wake and of the sucking flow for a single (isolated) hull depend on the geometrical characteristics of the hull $(B_1/T;\ L/B_1;\delta)$ and these values depend on the loading coefficient K_{DE} of the screw propeller and they should be calculated by using Figure 6.7 and the formulas:

$$w = w\left(\frac{L}{B_1}; \frac{B_1}{T}; \delta; K_{DE}\right); \quad t = t\left(\frac{L}{B_1}; \frac{B_1}{T}; \delta; K_{DE}\right).$$

where δ is the block coefficient.

The parameters for the interaction coefficients k_{υ} and k_t of the interaction of the hulls of a catamaran depending on the coefficient of the screw wake and of the sucking flowing are the ratio L/B_1 of the catamaran's hulls, the relative clearance $2\bar{b}$, the Froude number $\mathrm{Fr} = \frac{\upsilon}{\sqrt{gL}}$ and the coefficient K_{DE}. They can be defined by using the Figure 6.8.

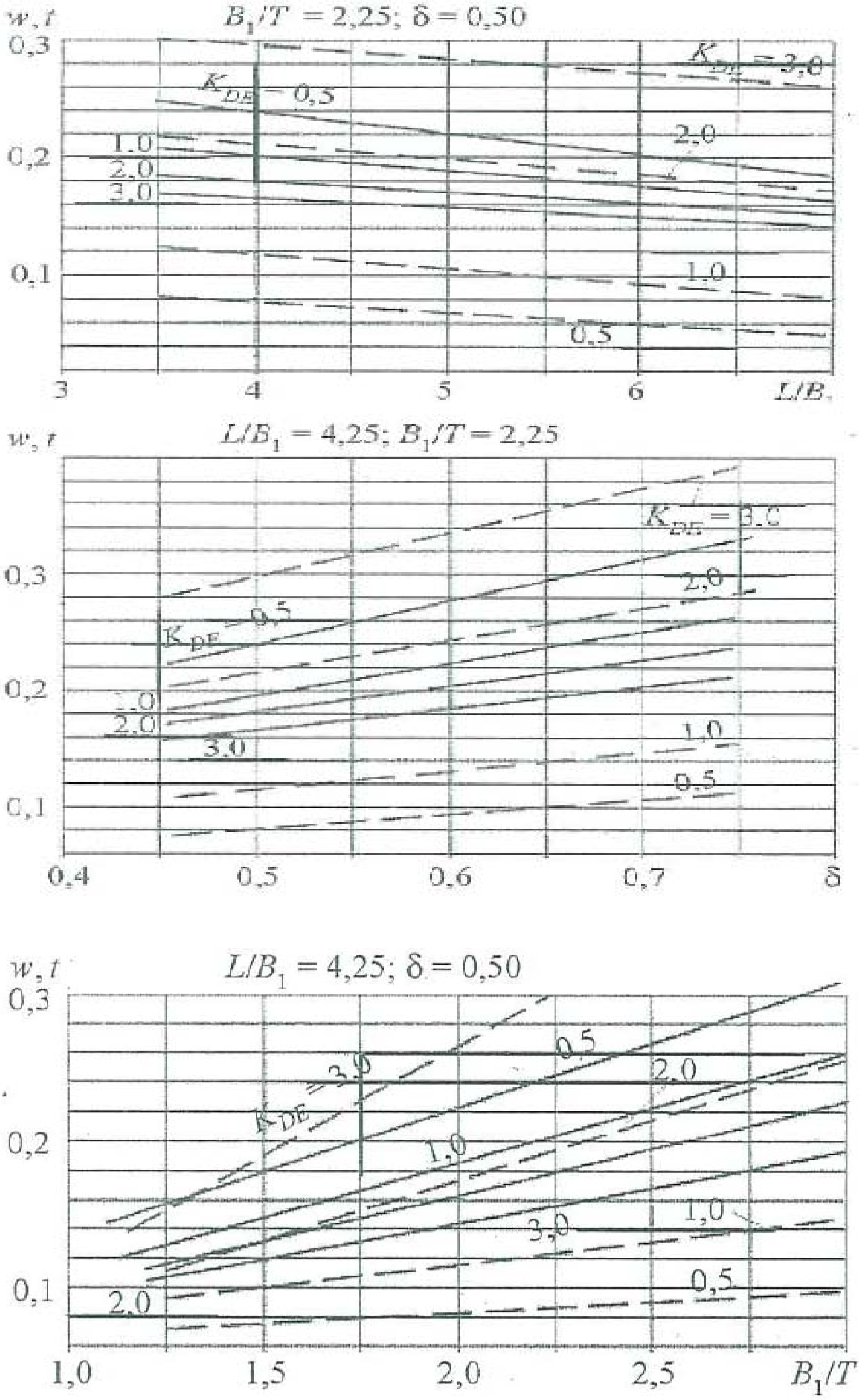
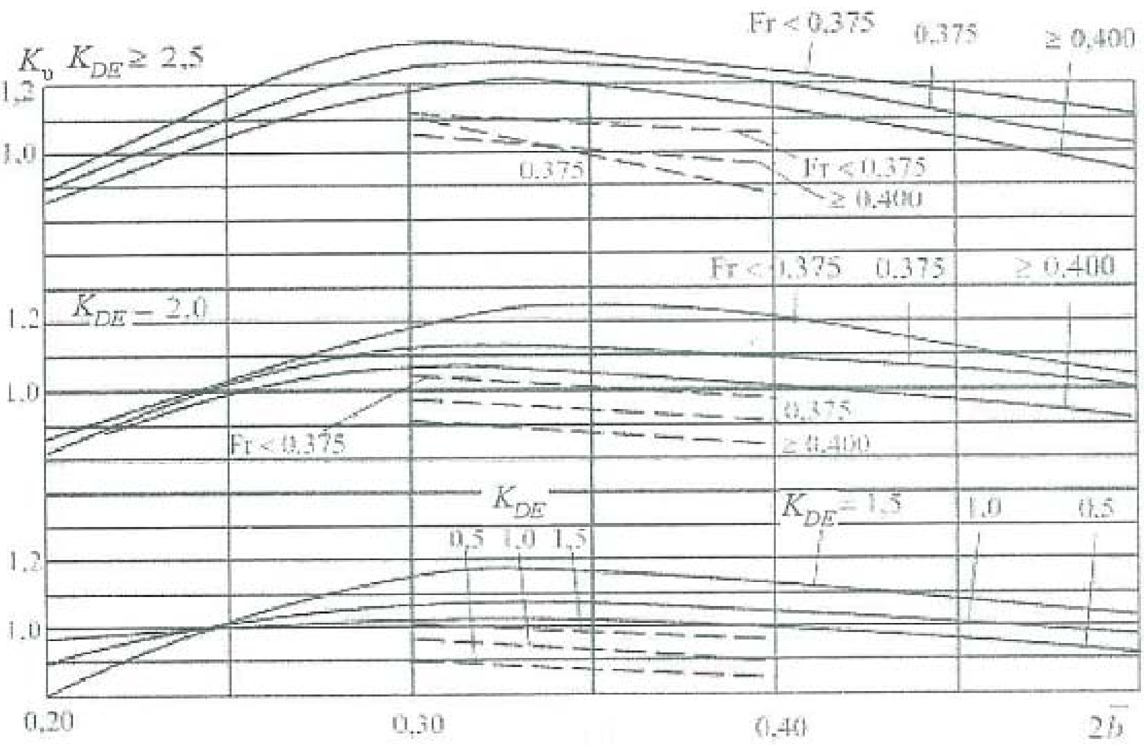
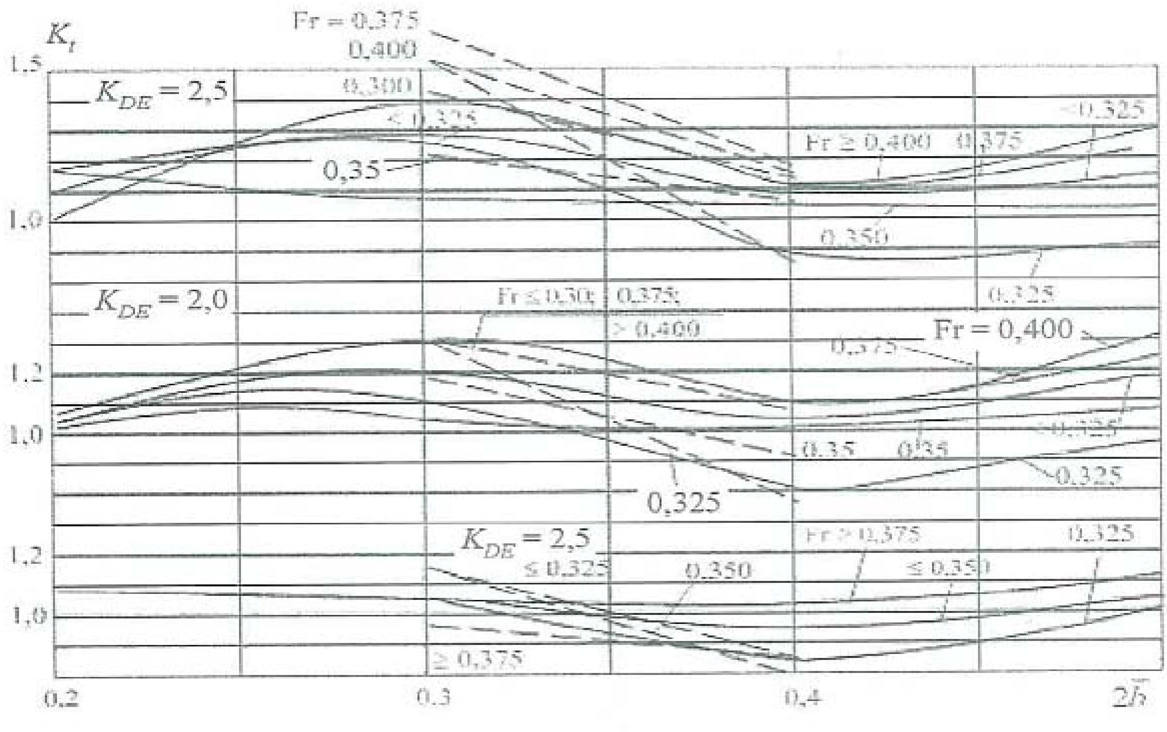


Figure 6.7. Coefficients of the screw wake ***ω*** (———) and of the sucking water flow ***t*** (- - -) of a single (isolated) hull of a catamaran.

(Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).



a



b

Figure 6.8. ***a)*** Coefficients of the screw wake and ***b)*** of the sucking flow of the hulls

of a catamaran.

(Ref. - Слижевский Н.Б., Король Ю.М., Соколик М.Г., "Расчёт ходкости быстроходных судов и судов с динамическими принципами поддержания", Научное пособие, НУК, Николаев, 2007).

Example of calculation of the propulsive quality of a catamaran.

Table 6.1. Input data to calculation example.

Input data:

Volumetric displacement, m^3:	
- total V	930;
- one(single) hull V_1	465;
Speed υ_S, knots	11;
Speed υ_S, m/s	5,654;
Length on a waterplane (WL) L, m	35,0;
Width, m:	
- total B_m	20,2;
- one (single) hull B_1	6,7;
Depth T, m:	3,6;
Ratios:	
- L/B_1	5,22;
- B_1/T	1,86;
Block coefficient δ	0,550;
Prismatic coefficient φ	0,633.
Transverse clearance: $2\bar{b} = 2\frac{b}{L} = 2\cdot\frac{7,75}{35,0};\quad 2\bar{b} = 0,443.$	0,443;
Towing resistance R, (kN)	57,2;
Tow-rope power of a catamaran P_E, (kW)	646,8
Tow-rope power of the single hull of a catamaran P_E, (kW)	323,4 (a single hull is used for the following calculations)
Froude number $\mathrm{Fr} = \frac{\upsilon}{\sqrt{gL}} = 0,054\upsilon$	0,305

NOTE: Input data is based (Table 6.1) on the parameters from the Input data (Table 4.3) (Chapter 4) and on the data, which were received from the calculations in Table 4.4.

Calculations of the subsidiary quantities.

- The diameter of the screw propeller, m:

$$D = (0,68...0,75)\cdot T = (0,68...0,75)\cdot 3,6 = 2,57.$$

- The loading coefficient of the screw propeller:

$$K_{DE} = D\upsilon\sqrt{\frac{\rho}{R_1}} = 2,57\cdot 5,65\sqrt{\frac{1,025\cdot 2}{57,2}} = 2,75.$$

- Number of the blades ($K_{DE} \geq 2$):

  $Z = 3$.

- The blade-area ratio:

$$A_E/A_0 = 0,35.$$

NOTE: the blade-area ratio is taken as a relevant assumption in this example from the source: ***"Расчёт ходкости надводных водоизмещающих судов"/ Н.Б. Слижвский, Ю.М. Король, М.Г. Соколик; Под ред. Н.Б. Слижевского. - Николаев: НУК,2004.***

- The coefficient of the screw wake and of the sucking flow of the single (isolated) hull:

$\omega = \omega\ (L/B_1 = 5,22,\ B_1/T = 1,86;\ K_{DE} = 2,75;\ \delta = 0,550) = 0,140;$

$t = t\ (5,22;\ 7,86;\ 2,75;\ 0,550) = 0,250$ (see Figure 6.7).

- The influence coefficient of the hulls interaction depending on the screw wake k_V and the sucking water flow k_t:

$$k_V = k_V\left(\frac{L}{B_1} = 5,22;\ 2\bar{b} = 0,443;\ Fr = 0,305;\ k_{DE} = 2,75\right)$$

  $k_V = 1,20;$

  $k_t = k_t(5,22;\ 0,443;\ 0,305;\ 2,75);$

  $k_t = 1,10$ (see Figure 6.8).

- The coefficient of the screw wake ω_k and of the sucking flow t_k

  $\omega_k = \omega\cdot k_V = 0,140\cdot 1,20;$

  $\omega_k = 0,168;$

  $t_k = t\cdot k_t = 0,250\cdot 1,1;$

  $t_k = 0,275.$

- The calculated speed at the disk of the screw propeller υ_A, m/s:

$\upsilon_A = \upsilon \cdot (1 - \omega_k) = 5{,}65 \cdot (1 - 0{,}168)$;

$\upsilon_A = 4{,}70$ m/s.

- The screw propeller thrust T_B, kN:

$T_B = R/2 \cdot (1 - t_k) = 57{,}2/2 \cdot (1 - 0{,}275)$;

$T_B = 39{,}45$ kN.

The further calculation is made in tabular form (Table 6.2) for a range of the diameter values of the screw propeller $\boldsymbol{D}$ = (2,3…2,9) m for the chosen speed υ_s = 11knots (5,654m/s).

Table 6.2. <u>Calculation of the propulsive quality of a catamaran in a still water.</u>

Item and size	Numerical value			
Diameter values of the screw propeller D, m	2,60	2,70	2,80	2,90
The loading coefficient of the screw propeller depending on the thrust $K_{DT} = D\upsilon_A\sqrt{\frac{\rho}{T_з}} = 0{,}758D$	1,97	2,05	2,12	2,20
$J = J(K_{DT})$*	0,78	0,81	0,825	0,860
$P/D = P/D(K_{DT})$*	1,06	1,09	1,11	1,15
$\eta_\circ = \eta_\circ (K_{DT})$*	0,710	0,715	0,720	0,725
The rotational speed $n = \upsilon_A \times 60/(J \times D) = 4{,}70 \times 60/(J \times D) = 282/(J \times D)$ rpm**	139,1	128,9	122,0	113,1
The propulsive coefficient $\eta = (1-\omega_k) \times \eta_\circ /(1-t_k) = 0{,}871 \times \eta_\circ$	0,618	0,623	0,627	0,631
The efficiency of the reducer (a two-stage reducer) $\eta_r = 0{,}995$*	0,995	0,995	0,995	0,995
The efficiency of the shafting $\eta_s = 0{,}970$*	0,970	0,970	0,970	0,970
The required power of the one main engine P_S, (kW) $P_S = P_E /(Z_B \times \eta \times \eta_r \times \eta_s) = 323{,}4/(2 \times 0{,}955 \times 0{,}970 \times \eta) = 174{,}7/\eta$	282,7	280,0	278,6	276,9

***** -these coefficients are taking according to the graphs and input data from the source:*"**Расчёт ходкости надводных водоизмещающих судов"/ Н.Б. Сліжевский, Ю.М. Король, М.Г. Соколик; Под ред. Н.Б. Слижевского. - Николаев: НУК, 2004.***

*****- rpm*** = revs per minute= revolutions per minute.

The selection of the main engines is carried out according to the results of calculation (as an example in Table 6.2 above) and according to the recommendations and graphs from the source, such as: ***:"Расчёт ходкости надводных водоизмещающих судов"/ Н.Б. Слижевский, Ю.М. Король, М.Г. Соколик; Под ред. Н.Б. Слижевского. - Николаев: НУК, 2004.***

*Therefore, the bigger the draft of the vessel, the bigger the size of the diameter of the screw propeller will be (**D** = (0,68...0,75)·**T**). Hence, the value of the required power of the one main engine is decreasing. Catamaran has 2 main engines, one at each hull.*

CHAPTER 7: FABRICATION OF MULTIHULL VESSELS.

In this chapter the discussion will be about the possibilities of the fabrication & construction of a catamaran and trimaran vessels at shipbuilding plants of Ukraine, and also about opportunities of transportation & shipping of the given vessel class from the Black Sea through the Straits of Bosporus and Dardanelles. The shipbuilding plants of Ukraine have a long and rich history and therefore professionals, well educated and experienced shipbuilders, engineers and workers are working in the shipbuilding branch. Fabrication in Ukraine means that fabrications in large professional plants with similar characteristics are possible.

During the last century the shipbuilding plants of Ukraine have been building more than 1000 ships and vessels of different types and purpos: fleet destroyers, ships of the line, submarines, cruisers, ice-breakers, tug boats, whale factory vessels, bulk carriers, research vessels, floating bases for missile weapons, floating bases for submarines, floating workshops, vessels with horizontal cargo-processing, antisubmarine ships, super trawlers for fish transportation, bottom research vessels, aircraft carriers, tankers and tens of thousands of machines, boilers and equipment for various purposes.

The vessels of the shipyards were exported to Sweden, Bulgaria, Norway, Romania, Great Britain, Germany, Portugal, Kuwait, India, Greece, etc.

The shipbuilding industry in Ukraine consists of eight major shipyards along with several large suppliers of marine equipment.

Some examples of *the shipbuilding plants of Ukraine*: “CHERNOMORSKY SHIPBUILDING YARD”, "SHIPYARD NAMED AFTER 61 COMMUNARDS",THE OKEAN SHIPYARD («OKEAH»), “KHERSON SHIPBUILDING YARD”, FEODOSIA SHIPBUILDING COMPANY "MORYE", “LENINSKA KUZNYA” PLANT, ZALIV SHIPBUILDING PLANT NAMED AFTER B. BUTOMA, THE SEVASTOPOL MARINE PLANT “ SEVMORZAVOD”, etc.

Over 80 percent of ship production takes place in the southern city of Nikolayev. Nikolaev has three large shipyards that take orders for delivery of any type of vessel: the shipyard "Okean", the Chernomorsky shipbuilding yard and the "61 Communard" shipyard. Nikolaev is located in the southern part of Ukraine, about 500 km south-east from Kiev, 120 km from Odessa and 60 km from the Black Sea on a peninsula formed by the Southern Bug and Ingul rivers (see Figure 7.2). Through the Dnieper - Bug Estuary Nikolaev is connected with the Black Sea and the great Ukrainian river Dnieper. This has made it possible to locate sea and river ports in Nikolaev.

All over the world Nikolaev (Mykolaiv) is well known as a city of shipbuilders.

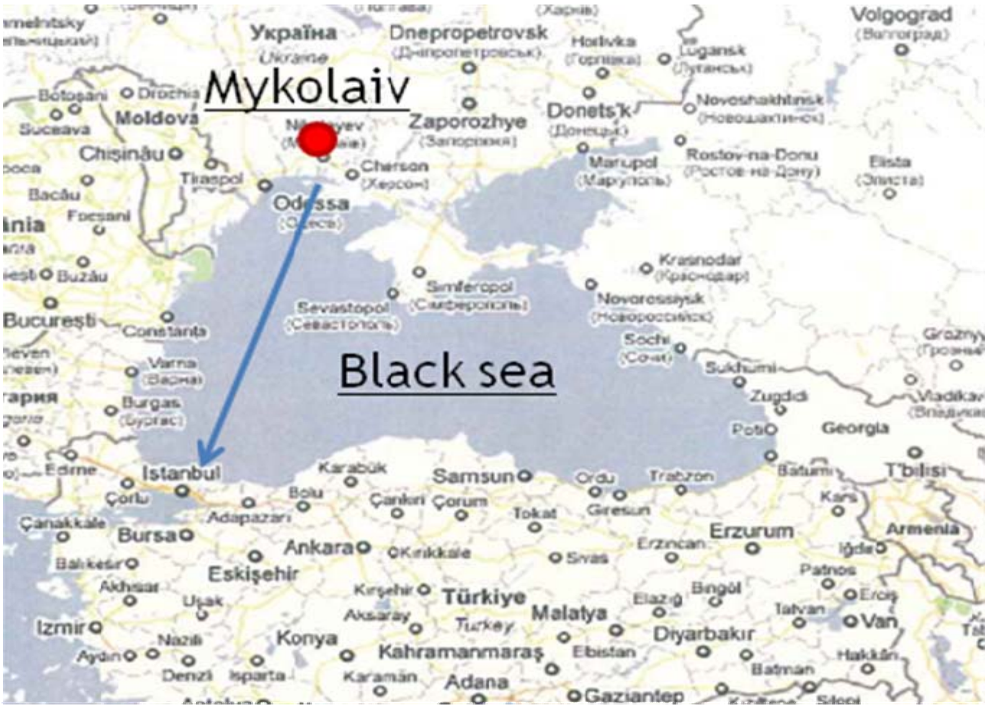


Figure 7.1. The location of Mykolaiv*, Ukraine. (Ref. - **http://images.google.no/imgres?imgurl=http://upload.wikimedia.org/wikipedia/commons/e/ed/Map_of_Ukraine_political_enwiki.png).**

* ***NOTE:*** ***Nikolaev (Russian=Николаев);***

Mykolaiv (Ukrainian=Миколаїв).

All plants which are listed above are cooperating with each other in the various projects and directions; all of them are connected to each other by the Black sea or rivers, by transport and also by the trains. The shipbuilding plants are cooperating with each other by building sections of the vessels, by using their equipment, according to the different possibilities of the shipbuilding factories.

Strong ties link Nikolaev closely to merchant fleet and the Navy, due to the location of the three shipyards, where vessels and ships of various types, from bulk-oil carriers to aircraft carriers have been under construction. Approximately 75 industrial enterprises are connected with the shipbuilding. Gas turbines, air conditioning systems, machine tools, conveying and metal cutting machinery produced in Nikolaev operate in different enterprises of marine technology and industry. The heavy industry has suffered from the reduction of military orders and rupture of links with former Soviet republics. Now they are facing the problem of reconversion and privatisation and spin-off companies are established on their base creation. (Ref. - **http://www.globalsecurity.org/military/world/russia/chernomorsky.htm).**

Figure 7.2. A satellite photo of Mykolaiv in Ukraine and the location of the shipbuilding plants.
(Ref. - http://commons.wikimedia.org/wiki/Category:Mykolaiv)

1 - **The "61 Communards" Shipbuilding Plant;**

2 - **The Chernomorsky Plant;**

3 - **The "Ocean" Shipyard.**

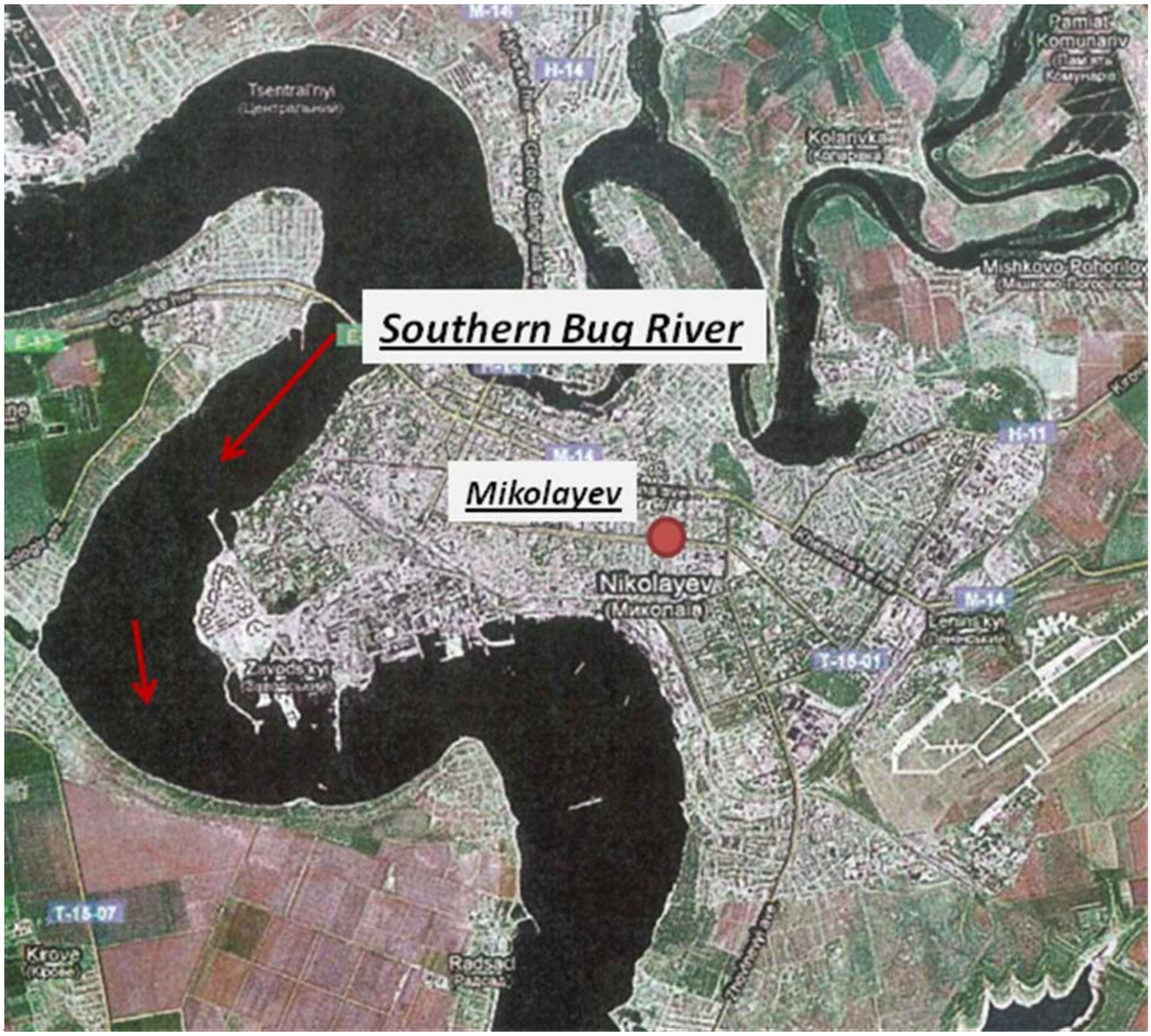


Figure 7.3 A Google map of Nikolaev (Ref. - http://maps.google.com/maps).

We will discuss more precisely and more deep some examples of the shipbuilding plants from those listed above.

The Chernomorsky Plant, Mykolayev, Ukraine.

The Chernomorsky Shipbuilding Yard was founded in 1897 and is now a major integrated shipbuilding and machine-building enterprise (including metallurgy) in Europe and in the world. The shipyard possesses a high level of autonomy and specializes in manufacturing of military ships and civil vessels of different purposes, machines, machinery, boilers, ship equipment, machinery and equipment for various branches of industry. The yard has built a variety of different vessels and ships in its history, including cruisers, destroyers, submarines, ice breakers, tankers, cargo ships, trawlers, research vessels and aircraft carriers. The shipyard is pride are battleships and cruisers, the first in the world submarine mine-layer "Crab", which increased the strength of the Black Sea Fleet during the World War II. This manufacturer was the only enterprise in the former

USSR, which possessed the manufacturing capacities and who performed the construction of high-powered aircraft-carriers of various types with length more than 300 m.

Famous vessels, such as ***"Moskva"***, ***"Leningrad"***, ***"Kiev"***, ***"Minsk"***, ***"Novorossiysk"***, ***"Tbilisi"***, ***"Baku"*** and the most powerful fighting ship for the Russian Navy, i.e. the heavy aircraft-carrying cruiser "***Admiral Kuznetsov***" (see Figure 7.4), were made by the Chernomorsky Shipbuilding Yard. The development of the construction of these heavy aircraft-carrying ships required new fabrication technologies that were developed by the Chernomorsky shipbuilding yard.

Figure 7.4. Russian aircraft carrier "Admiral Kuznetsov".

(Ref. - **http://en.wikipedia.org/wiki/File:Russian_aircraft_carrier_Kuznetsov.jpg.jpg**)

Admiral Kuznetsov (Russian: Адмирал Кузнецов) is an aircraft carrier (heavy aircraft carrying cruiser in the Russian classification) serving as the flagship of the Russian Navy. The start of construction took place on September 1, 1982; in fact she was laid down in 1983; was launched in 1985, and became fully operational in 1995, see Figure 7.5 and Table 7.1).

Figure 7.5. “Admiral Kuznetsov” in drydock (under repairing above) and under construction (below) in 1984.

(Ref. - **http://en.wikipedia.org/wiki/Russian_aircraft_carrier_Admiral_Kuznetsov**)

Table 7.1. ***Key Data of the aircraft carrier "Admiral Kuznetsov":***

Dimensions:	
Length	***306.5 m***
Length at Waterline	***270 m***
Beam	***72.3 m***
Draught	***9.14 m***
Displacement	***65000 t full load***
Maximum Displacement	***58600 t***
Performance:	
Speed	***32 knots (≈59 km/h)***
Endurance:	***45 days***
Crew:	• ***1,960 ship's crew 626 air support group*** • ***40 flag staff*** • ***3,857 rooms***
Weapon Systems:	• ***12 x Granit anti-ship missiles*** • ***24 launchers and 192 vertical launch missiles; (1 missile per 3 seconds)*** • ***4 x combat modules*** • ***256 missiles and 48,000 cartridges*** • ***60 rockets***
Propulsion:	• ***Steam Turbine: 6 x 1,500kW*** • ***Boilers: 8*** • ***Propellers: 4 x fixed-pitch propellers*** • ***Capacity Turbo-generators 9 x 1,500kW*** • ***Generating Capacity Diesel Generators (6 x 1,500kW)***
Aircraft:	***Fixed Wing:*** • ***16 x Yakovlev Yak-41M (Yak-141) 12 x Sukhoi Su-27K (Mikoyan-Gurevich MiG-29K)*** ***Rotary Wing*** • ***4 x Kamov-27 helicopters*** • ***18 x Kamov-27 helicopters*** • ***2 x Kamov-27 helicopters***

(Ref. - http://en.wikipedia.org/wiki/Russian_aircraft_carrier_Admiral_Kuznetsov)

(Ref. - http://www.naval-technology.com/projects/kuznetsov/specs.html)

The Chernomorsky Shipbuilding Yard's largest slipway is 330 m long and 40 m wide and two cranes of 900-ton lifting capacity each are able to handle sections of more than 1,500 tons (see Figures 7.5 and 7.6). The main part of the shipyard are the following work-shops: the slipway work-shop, the outfitting work-shop, the plating work-shop, the work-shop for assembly and welding of flat and volumetric sections. The assembly and welding work-shop is designed to fabricate volumetric block-sections up to 180 tons, which during manufacturing are outfitted with welded parts and piping in double bottom and double sided compartments. Modern technologies of metal cutting and welding, use of standardized elements, improvements of dimensional accuracy, introduction of integrated automation lines and modularized out-fitting of rooms enable one to realise flexible methods of construction of any ship project and adapt easily to technical requirements.

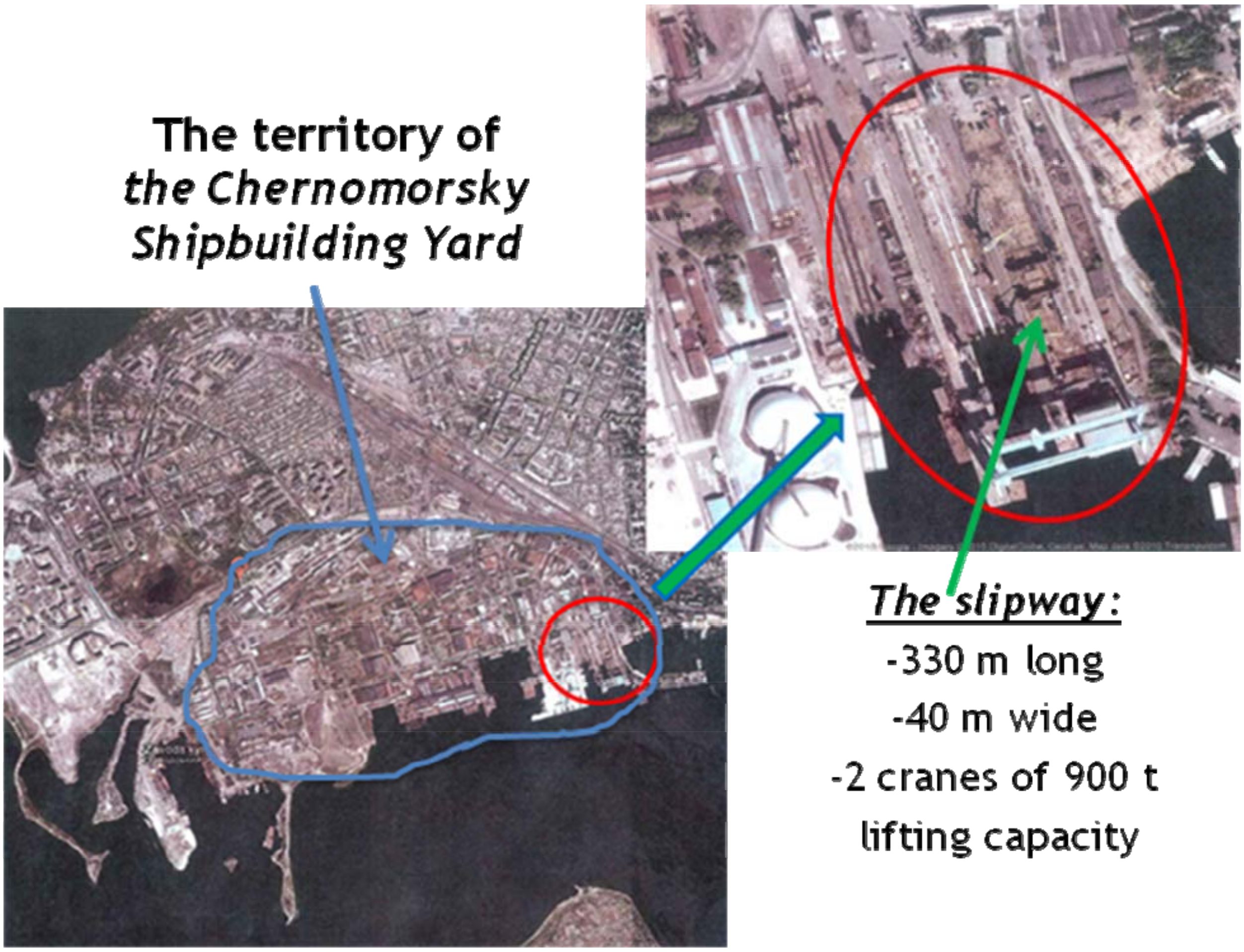


Figure 7.6. The Chernomorsky Shipbuilding Yard and the largest slipway of the plant.

(Ref. - http://maps.google.com/maps).

The Chernomorsky Shipbuilding Yard possesses unique technologies, which were developed and adopted by the specialists with involvement of the leading scientific institutes:

- Exact contouring of sections and blocks of the vessel
- Method of a large-block shipbuilding
- Simultaneous building of a series of medium-tonnage vessels in a sheltered slipway
- Manufacturing of propeller shafts with lengths up to 30m
- Manufacturing of one unit-cast and welded anchor chains etc.

The development of the shipbuilding projects, the contacts, the release of the structural documentation and technical description of the construction are performed by the yard's own design center. The center is supplied with the qualified engineering staff, modern computer equipment and uses a system of total automated construction and shipbuilding during engineering and construction of vessels.

The total area of ***The Chernomorsky Shipbuilding Yard*** (***CSY)*** (see Figure 7.7) is approximately 300 hectares, with a branched network of railways (43km) and automobile ways (29km).

Figure 7.7. The territory/the work-shop area of the Chernomorsky Shipbuilding Yard.

(Ref. - **http://maps.google.com/maps).**

The shipyard is specialized in construction of medium- and heavy-tonnage vessels of various types and purposes with capacity of processing a single hull's metal volume up to 60 000 t and welded structures near 30 000 t. The metal-processing workshops are equipped with modern technologies of cutting and metal welding, with flow lines for processing of the rolled metal, with a ESAB line for production of the flat sections and coatings. The facilities of the assembly-welding workshop allow fabrication of large block-sections with a weight up to 180 t with welding and piping.

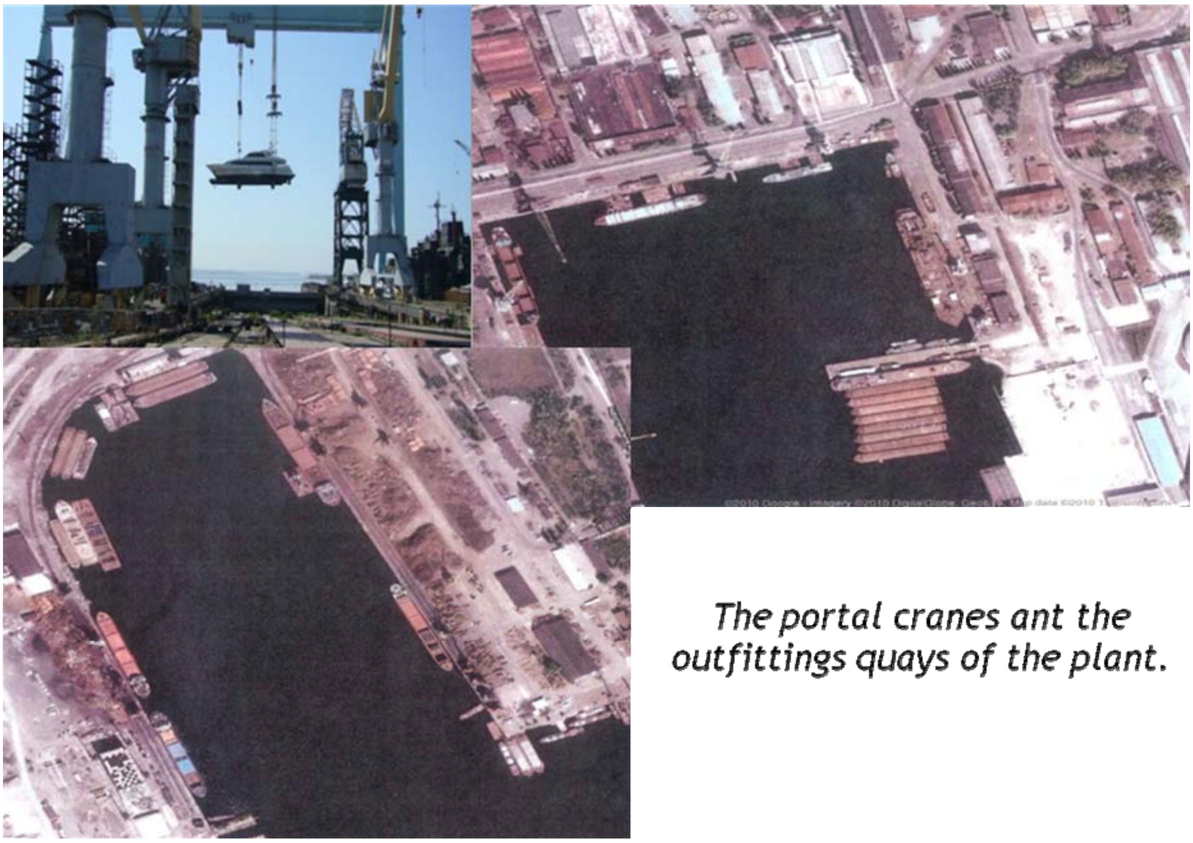
For the launch of vessels the shipyard has *2 inclined slipways*, which allow launching t vessels with weight up to 24 000 t from the largest slipway and up to 10 000 t from the other slipway. Herewith the largest slipway has 2 gantry cranes (see Figure 7.8) with a lifting capacity of 900 t each and a high-capacity pre-slipway area with an area of 14 000 m^2, where the assembling of the blocks with weights up to 1500 t is possible.

Figure 7.8. The slipway and the cranes of the plant.

(Ref. - **http://maps.google.com/maps).**

The out-fitting is performed afloat near 3 outfitting quays with a total length near 860 m, which are equipped with portal cranes with a lifting capacity of 25-40.

The shipbuilding is performed on a flow-position line, which is located in a sheltered slipway with length 400 m and actually is a closed-loop autonomous production line. Launching of vessels in the flow-position line is effected with the help of the floating dock with a lifting capacity 7500 t, length 120 m and breadth 41.5 m, whereupon the vessels pass the final out-fitting near the South outfitting quay with length 546 m (see Figures 7.8 and 7.9).



The portal cranes ant the outfittings quays of the plant.

<u>Legend</u>: see next page.

Figure 7.9. The outfitting quays, the slipway supports and the cranes of the plant.

(Ref. - http://maps.google.com/maps).

Currently ***the Chernomorsky Shipbuilding Yard*** has experience and reputation for construction of tankers for transportation of crude oil and heavy oil products, as well as product tankers. Technical resources of the plant allow building of these vessels with deadweight 45000-105000 tons. The manufacturing capacities of the hull processing workshop allow to perform processing of plates in the volume of 45000 t and profiled iron in the volume 15000 t, which secures its own needs and makes it possible to perform metal processing for other Ukrainian shipbuilding enterprises. The assembly welding workshop is also capable to perform the fabrication of hull constructions for other shipbuilding enterprises.

Piping production, which includes the whole cycle of fabrication (cutting, bending, galvanic handling, painting, insulating, performance of hydraulic tests, and X-raying) and fitting of the ship's piping make is possible to perform the manufacturing program of ***the Chernomorsky Shipbuilding Yard*** as well as fabrication of piping for other enterprises. A workshop effectuates the fabrication and mounting of systems and products from steel, copper, copper-nickel, bimetallic, rustproof and other piping.

Table 7.2. Comparison of the volume and the width of the Chernomorsky Shipbuilding yard, trimarans and catamarans.

Shipbuilding plant	Width	Volume
The Chernomorsky Shipbuilding Yard	40 m	Up to 60000 t
Trimaran	Up to 36 m	Typically up to 5000 t
Catamaran	Up to 22 m	Typically up to 5000 t

As we see from the information and from the table listed above ***the Chernomorsky Shipbuilding Yard's*** *opportunities, the building and construction of the catamarans/ trimarans is real.*

(Ref.-**http://www.globalsecurity.org/military/world/russia/chernomorsky.htm)**

(Ref. - **http://www.chsz.mksat.net/index.php?option=com_content&view=article&id=51&Itemid=55&lang=ru**)

The “61 Communards” Shipbuilding Plant, Mykolaiv, Ukraine.

"***The Shipyard named after 61 Communards***" is situated in the city of Nikolaev* on the banks of the Ingul river, 55 miles from the Black sea.

* ***NOTE:*** ***Nikolaev (Russian=Николаев);***

Mykolaiv (Ukrainian=Миколаїв).

Established in Nikolayev in 1788, the history of the "61 Communards" shipyard is closely linked with the history of the Black Sea Navy. The birth of the yard took place in 1788- a year earlier than that of Nikolaev itself- and was caused by the necessity to strengthen the southern frontiers of the Russian Empire and to create a strong navy. The yard has built a variety of different vessels and ships of different types and purposes: torpedo-boat destroyers, destroyers and submarines, supply vessels for Navy, including rescue vessels of various purposes equipped with deep-water operation systems. About one third of Navy of former USSR was built at the ***“61 Communards” shipyard***.

The total area of the enterprise is 1414.5 m^2, with built up area of 476.5 m^2. Production capacities of the enterprise are concentrated in 286 industrial buildings and 165 industrial structures (see Figure 7.10).

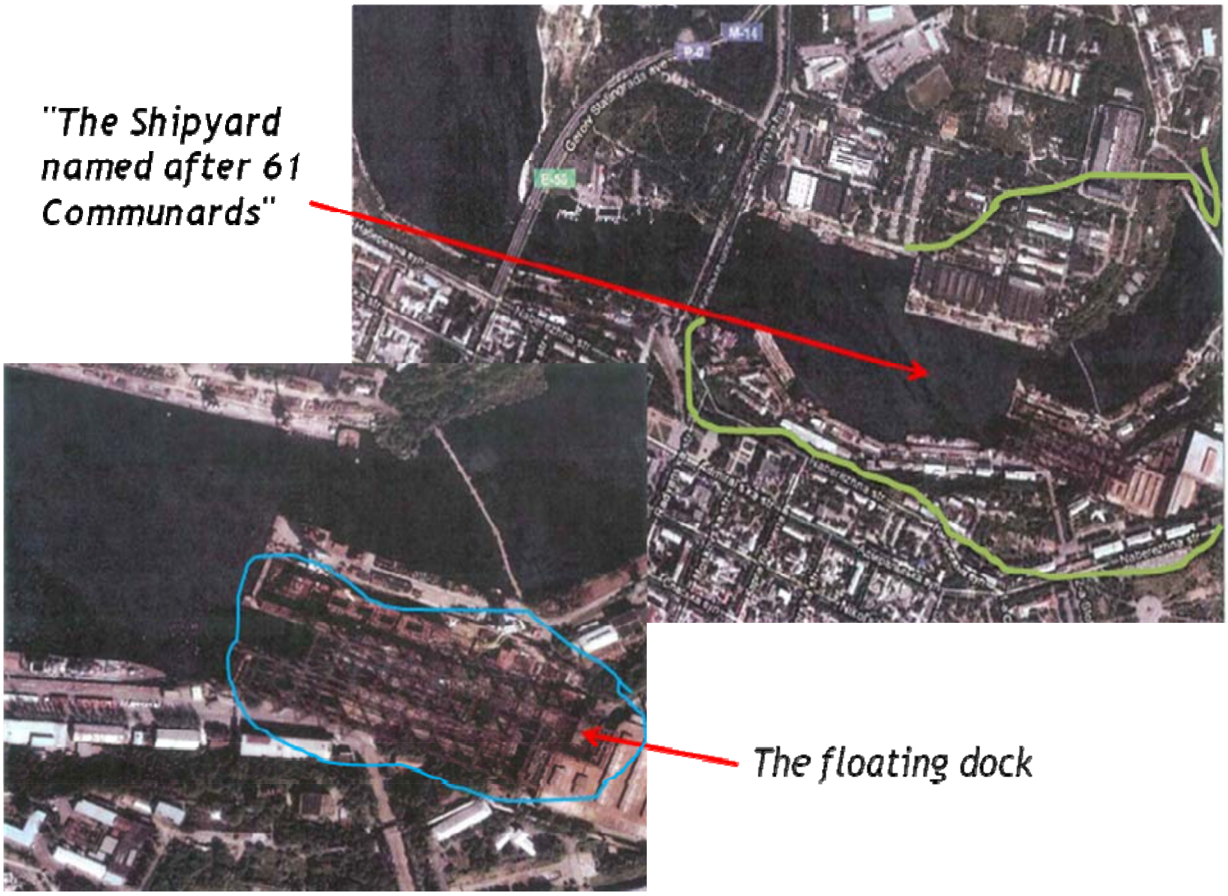


Figure 7.10. The territory/the work-shop area of "The Shipyard named after 61 Communards".

(Ref. - **http://maps.google.com/maps).**

Technological and organizational possibilities of the shipyard allows to build contemporary, highly efficient and reliable vessels of all types with hull weights up to 28 000 t. Construction of hulls is made on three building berths with partial installation and mounting of equipment and machinery simultaneously.

The total length of wharfs equipped with necessary infrastructure makes 1248 m. That allows to outfit simultaneously no less than 10 vessels.

Production capacities of the pipe machining, mechanical mounting, electrical engineering, paint and insulation, woodworking and machine building workshops involved in the process of shipbuilding and ship repair are sufficient without enlisting a contractor.

A floating dock of 7000 t lifting capacity allows to perform any kind of ship repair for ships of up to 140 m length and up to 25 m width (see Figure 7.12).

In connection with conversion the excessive production areas (20000 m^2), covered terminals to keep and handle different kinds of cargo (30000 m^2), terminal equipped for keeping, receiving and giving out luboil and fuel (10000 m^2) are available at the shipyard.

(Ref. **- http://www.globalsecurity.org/military/world/russia/61communards.htm).**

(Ref. - **http://www.shipyard61.com.ua/start-eng.html).**

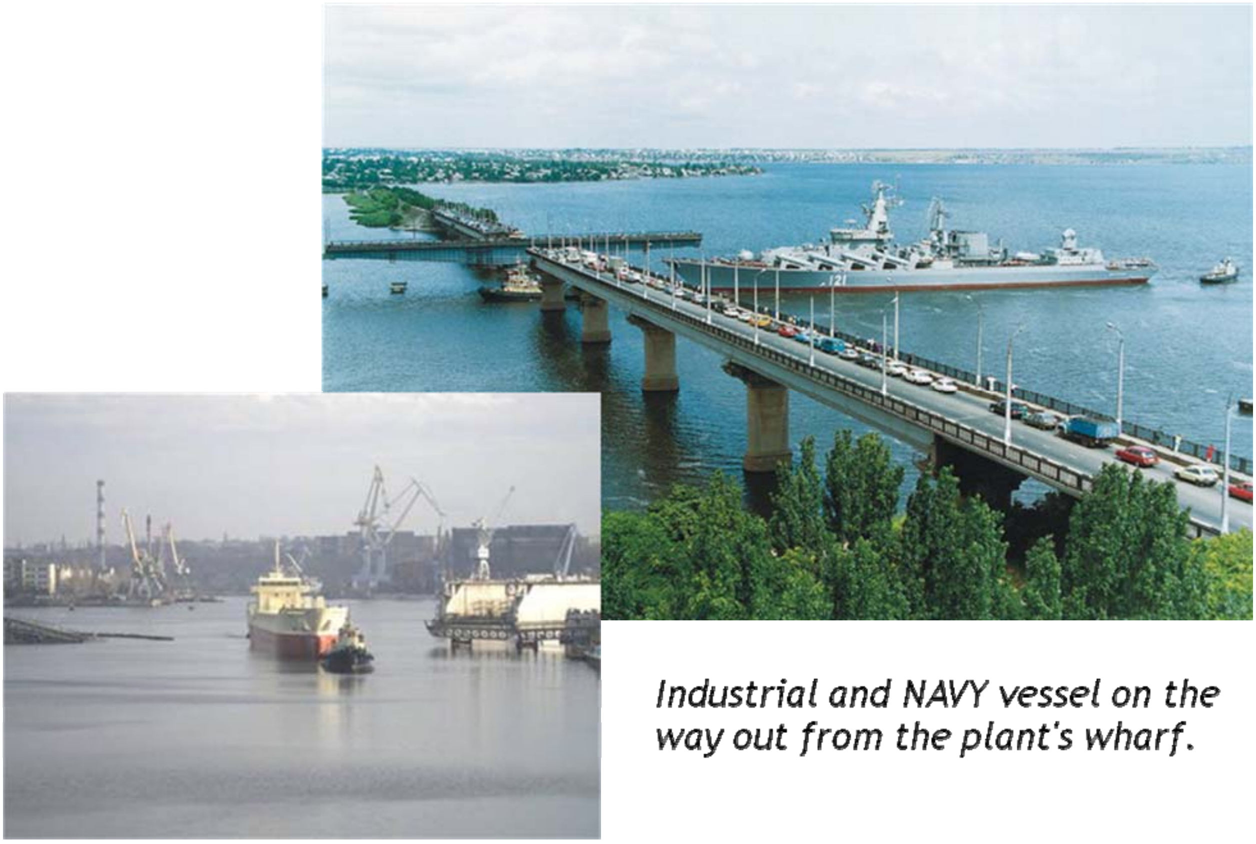


Figure 7.11. Industrial and NAVY vessels on the way out from the plant's wharf.

(Ref**.-** **http://www.shipyard61.com.ua/start-eng.html**)

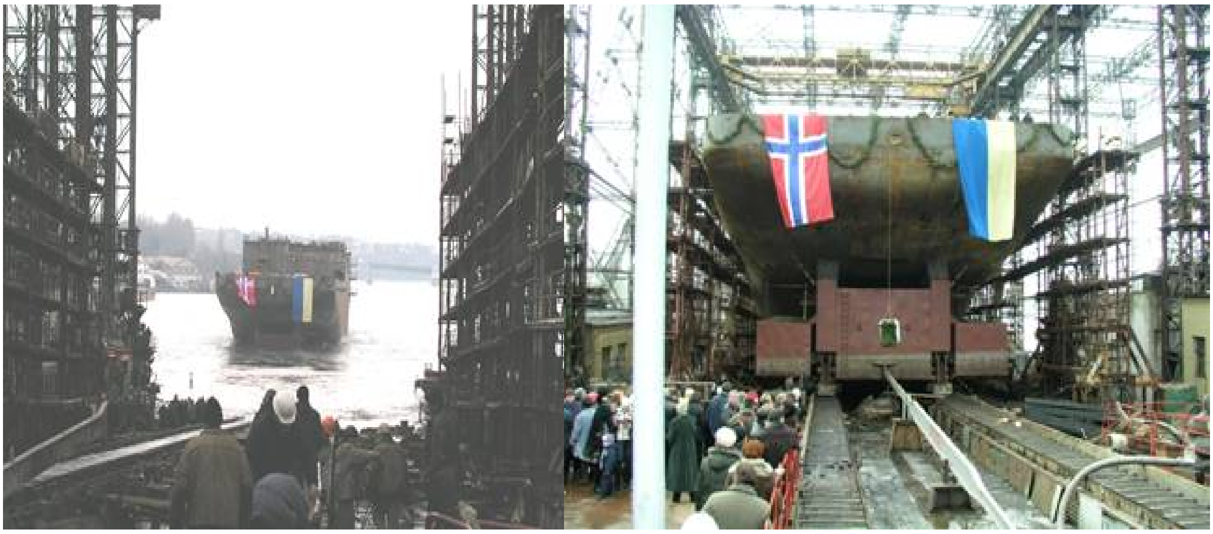


Figure 7.12. Double-way launching of the vessel.

(Ref. - **http://www.shipyard61.com.ua/start-eng.html)**

Figure 7.13. Cutting of the vessel’s supports.

(Ref. - **http://www.shipyard61.com.ua/start-eng.html**)

There are actually three large shipyards located in Mykolaiv: The Chernomorsky Shipbuilding Yard, the “Okean” Shipyard and the “61 Communards” Shipbuilding Plant.

The “Ocean” Shipyard.

*The **“Ocean” Shipyard*** (Завод «Океан) (see Figure 7.14) is located in Mykolaiv*, Ukraine and is the third major ship construction yard in the area. The ship-building facilities are situated in the estuary of the Bug river (~50 km from the Black Sea) on a site, which covers an area of 115.5 hectares and has allocated harborage of 57.3 hectares.

* ***NOTE:*** ***Nikolaev (Russian=Николаев);***
Mykolaiv (Ukrainian=Миколаїв).

The plant has 155 facilities, including the main production shops, open stock places, dry and floating docks, finishing quays, auxiliary production shops, storage areas and warehouses, acetylene and oxygen plants, a boiler house, office buildings, canteens, etc. The minimal distance from the site to the residential area is 400 meters. The “Okean” Shipyard has a good access to transportation routes, utilities supplies and other industrial infrastructure.

The plant was established in the 1950s and has specialized in large merchant ships to include the oil/ore carriers of the Boris Butoma class (130,000 DWT). The plant operates modern production facilities supplied by world known companies and has a medium and a heavy tonnage production line. The yard has constructed and delivered nearly 400 vessels of different types: non-self propelled barges, sea rescue tugs, timber-carriers, fish-processing factories, bulk carriers, research ships, merchant ships, tankers, etc.

Figure 7.14. The “Ocean” Shipyard. (Ref. - **http://maps.google.com/maps).**

The construction is carried out at two main production lines (see Figure 7.15). The heavy tonnage line includes assembly-welding workshop and dry dock (354 x 60 x 14m) with two frame cranes of 320 t lifting capacity, four portal cranes (80 t each) and out-fitting quay: 420 m (2 x 32 t capacity cranes). This production line can be used for constructing vessels with maximum dimensions 340 x 50x18m.

The medium tonnage line makes it possible to build vessels with maximum dimensions 150 x 22 x 11m and launch weight up to 5600 t and can mount catamaran/trimaran outside the dock. Outfitting quay – 210 m (2 cranes of 10t and 15 t capacities).

(Ref. - **http://en.wikipedia.org/wiki/Okean_Shipyard**).

(Ref.- **http://www.ifc.org/ifcext/spiwebsite1.nsf/1ca07340e47a35cd85256efb00700cee/8A4EA423958FC57F852576C10080CAC5).**

(Ref. - **http://www.stxeurope.com/?page=518).**

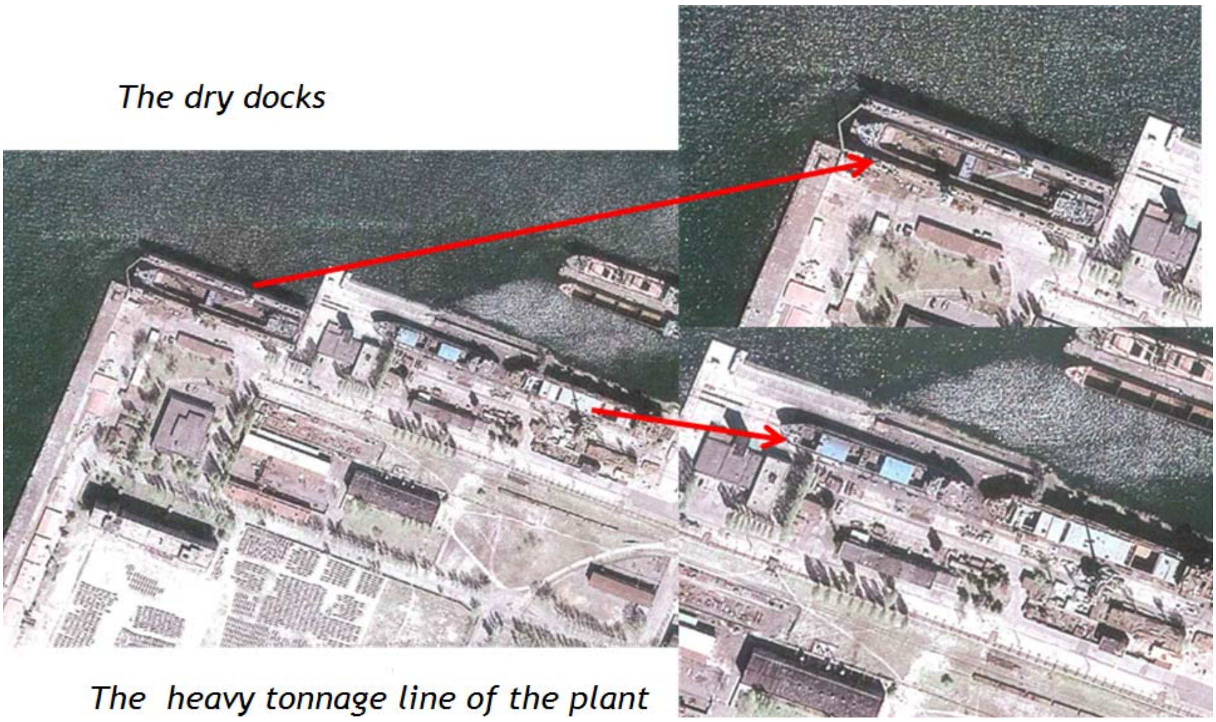


Figure 7.15. Two main production lines of the "Ocean" Shipyard.

(Ref. - **http://maps.google.com/maps).**

CONCLUSION: *Besides production facilities, Ukraine has notably professional labor and the sizable steel production volumes essential for shipbuilding. And as experience shows, particular success can be reached through joint activities with shipbuilders of Western Europe.*

As we see from the discussion above, the features of the plants in Ukraine allow the construction of vessels of various types and sizes, including catamarans and trimarans, which is meaning that the shipbuilding plants are able to mount such types of the vessels in the docks or in the slipways, same as by using the out-fitting areas of the plants. Further below, we will discuss opportunities and regulations of shipping a various sizes of the built vessels from the Black Sea area to the Mediterranean Sea via *the Bosporus Strait* and *the Dardanelles Strait* (see Figure 7.16).

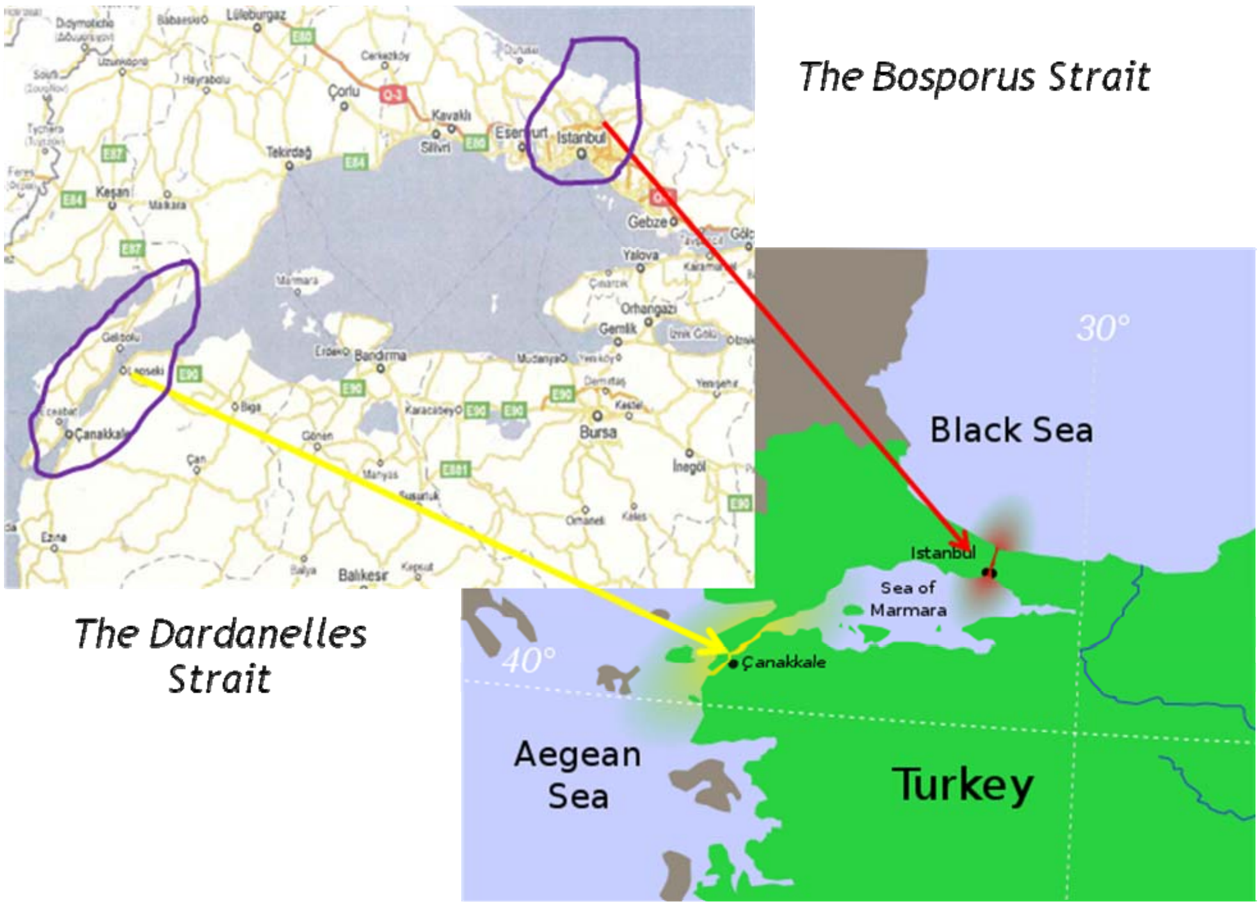


Figure 7.16. The map shows the location of *the Bosporus* (red) relative to *the Dardanelles* (yellow) and the *Sea of Marmara*.

- is the *Bosporus Strait* - is the *Dardanelles Strait*.

(Ref. - http://images.google.no/images?um=1&hl=no&tbs=isch%3A1&sa=1&q=the+Black+sea%2Cphotos&aq=f&oq=&start=0)

Oceanographic Information.

The Black Sea's seabed is divided into the shelf, the continental slope and the deep-sea depression. The shelf occupies a large area in the north-western part of the Black Sea, where it is over 200 km wide and has a depth ranging from 0-160 m. In other parts of the sea shelf has a depth of less than 100 m and a width of 2.2 to 15 km. The maximum depth of the Black Sea is 2,212 m. The surface area of the Black Sea is 432 000 km^2 with a total volume of 547 000 km^3 (State of the Environment of the Black Sea 2002).

(Ref. – **http://en.wikipedia.org/wiki/Black_Sea).**

The Black Sea is the most isolated sea in the World. It is connected to the World Oceans via *the Mediterranean Sea* through *the Bosphorus, Dardanelle and Gibraltar Straits* and with the Sea of Azov in the northeast through the Kerch Strait.
The physical characteristics of the Straits are not conductive to heavy traffic, more resembling a river at some points than an international waterway.

Satellite image of *the Bosporus Strait*; *the Dardanelles Strait* and *the Sea of Marmara*

Figure 7.17. Satellite image of the Sea of Marmara. (Ref. - **http://maps.google.com/maps).**

The Bosphorus is essentially a narrow elongated shallow channel approximately 32 km long, with a width changing from 0.7km to 3.5 km and a depth of 39-100 m (State of the Environment of the Black Sea 2002).The Strait is generally very narrow compared to other waterways in the world. There are two kinds of very strong currents along the Strait. These currents make marine traffic harder. There are furthermore some sudden turns along the Strait at almost 90 degrees. The Strait contains no less than 4 acute bends, 2 of them in less than 2 km, at a point where the Strait is only 700 m wide. There are 2 suspended bridges crossing the Strait (see Figure 7.19). The 3rd bridge is under construction.
The Bosphorus today is one of the world's busiest waterways. It is important strategically and politically since ancient times with its unique position that both links and separates the continents, depending upon how one looks at it, the Strait teems with a myriad of water vessels.While hundreds

of giant oil tankers and super cargo vessels pass through daily, commuter ferry boats rush between the two banks.Foreign flag ships, naval vessels, and Turkish cargo boats maneuver between the other ships. Add to this a population of fishing boats and wooden row boats and the Bosphorus becomes dangerously clogged.

Figure 7.18. Satellite image of the Bosphorus Strait. (Ref. - http://maps.google.com/maps).

The Bosphorus Strait Regulations.

In 1936 the Treaty, guaranteeing free passage in peacetime of the Bosphorus Straits was signed.The Treaty guarantees Turkey's sovereignty,but it states that in peacetime, vessels of any nation carrying any cargo may pass freely without delay or regulation through the Strait. In 1936,the large vessels, such as supertankers did not exist, and traffic through the Strait was minimal. For example, in 1936, an average of 17 ship passed each day, usually carrying grain, and weighing 1300 t. Nowadays, however, on average, 110 ships weighing as much as 200000 tons, often carrying oil, gas, chemicals, nuclear waste, and other hazardous materials, pass through the Strait each day.

In May 1994, the Turkish government, citing safety and environmental concerns, passed measures which would regulate the passing sea traffic through the Bosphorus Strait. The Regulations contained numerous provisions,such as:

- Vessels longer than 150 m are advised to take pilot captain and guiding tugs
- Automatic pilots for navigation are prohibited
- Ships powered by nuclear energy, or carrying nuclear or other hazardous materials must report to the Turkish Environment Ministry for permission
- Ship height is limited to 190 feet
- New traffic lanes were set and new traffic separation schemes were implemented

- No more than a single vessel carrying materials deemed hazardous will be allowed to pass at the same time
- All ships must notify Turkish authorities 24 hours in advance of intention to pass through the Strait
- Ships longer than 200 m can pass only in daytime
- Passage requires favorable weather

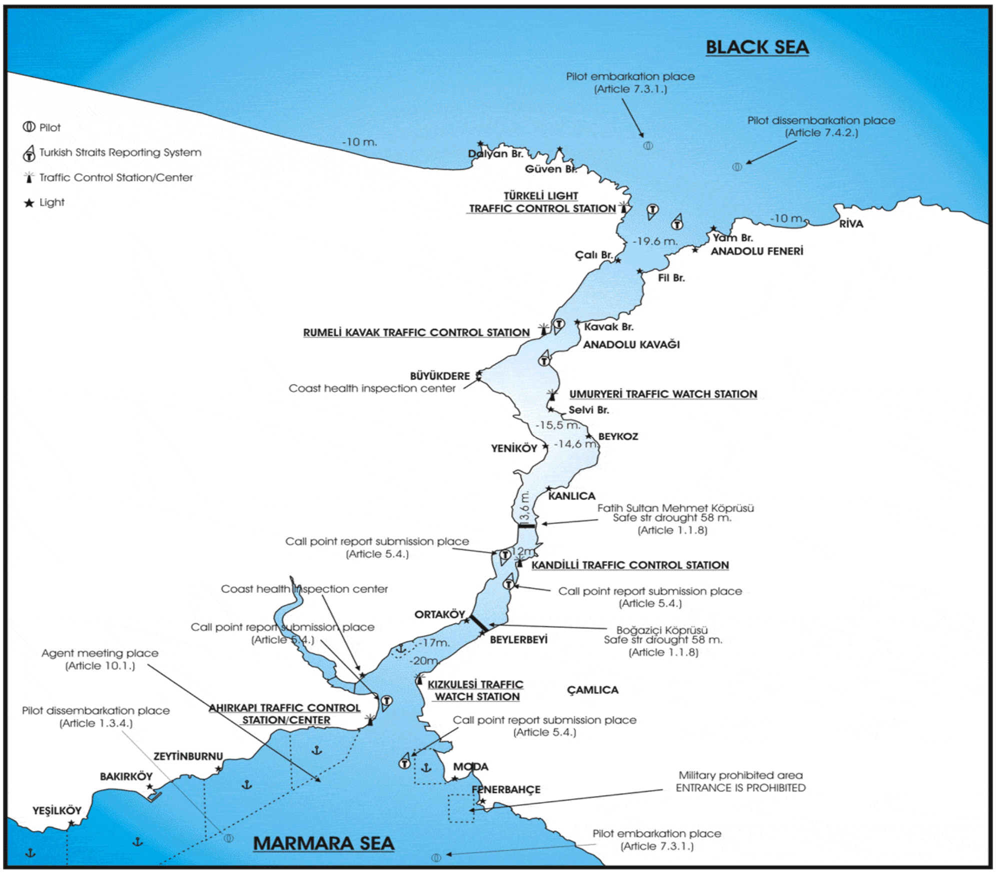


Figure 7.19. A map showing the depth variability of the Bosphorus Strait.

(Ref. - **http://www.cerrahogullari.com.tr/ports/BOSPHORUS%20(ISTANBUL)%20STRAIT%20.htm).**

Shortly after announcing the new regulations, Turkey approached the International Maritime Organization (IMO), an international unity linked to the United Nations, in an attempt to gain approval for the new measures.

For the vessels that are wide, the owner or operator of such vessels shall provide the administration with the info on the. (The Traffic Control Center and if necessary the administration, based on these data provided to them about the vessels , shall inform the relevant vessel's owner, the operator or the captain of the requirements and the recommendations, if any, that are necessary to ensure a safe passage of the vessel in question through the Bosphorus Strait, taking into account all specifications of the vessels , including their dimensions and maneuvering capabilities, the morphological and physical structure of the Bosphorus Strait, the condition of the season, the safety of life, property and environment as well as the maritime traffic).

The vessel must notify Turkish authorities at least 72 hours in advance of intention to pass through the Bosphorus Strait.

The heavy traffic through the Bosporus undoubtedly presents substantial risks to the local environment. If statistics of the number of vessels passing through the Strait are considered in relation to the physical characteristics of the Strait, it is abundantly clear that the probability of a serious environmental catastrophe occurring in or around Istanbul is very high. With the increase in oil traffic projects as a result of the exploration of the Central Asian oil fields, it is abundantly evident that it is unfair to ask Turkey to assume the risk for the health of both the environment of the Strait and the health of the inhabitants of the Bosphorus by requiring that all the oils is transported through the Bosphorus.

(Ref. - **http://en.wikipedia.org/wiki/Bosphorus)**

(Ref. - Master Thesis by Deniz Guney "Oil Transport Routes from Caspian Sea: Pipeline Project Course", Høgskolen i Stavanger, 1998).

The Dardanelles Strait.

The Dardanelles (Turkish: Çanakkale),see Figure 7.20, is a narrow Strait in northwestern Turkey connecting the Aegean Sea to the Sea of Marmara. The strait is 61 km long but only 1.2 to 6 km wide, averaging 55 m deep with a maximum depth of 82 m. Water flows in both directions along the strait, from the Sea of Marmara to the Aegean via a surface current and in the opposite direction via an undercurrent.

Like ***the Bosporus***, it separates Europe (the Gallipoli peninsula) from the mainland of Asia. The strait is an International waterway, and together with the Bosporus, the Dardanelles connects the Black Sea to the Mediterranean Sea. (Ref. - **http://en.wikipedia.org/wiki/Dardanelles**).

The Dardanelles Strait Regulations.

In *the Dardanelles*, vessels should keep to that side of mid-channel which lies on their starboard side, taking care to make sound signals in accordance with the rule when approaching the narrows of Canakkale and the bend of Nara. Vessels should also take every precaution to avoid meeting other vessels in the areas between Kilitbahir and Canakkale, between Nara and Kilia, between Gelibolu and Cardak (see Figure 7.21); and, when the current or weather is in their favor should give way to oncoming vessels by stopping or reducing speed.

The vessels that are 150-200m in length and/or whose draft is between 10-15m, shall notify Turkish authorities at least 24 hrs before their entry to the Turkish straits, the vessels that are 200-300 m in length and/or have more than 15 m draft, must notify Turkish authorities 24 hours in advance of their intention to pass through the Turkish Strait.

For the vessels that are more than 300 m in length, the owner or operator of such vessels shall provide the administration with the info on the vessel and its cargo during the planning phase of the

sail. (The Traffic Control Center and if necessary the administration, based on these data provided to them about the vessels, shall inform the relevant vessel's owner, the operator or the captain of the requirements and the recommendations, if any, that are necessary to ensure a safe passage of the vessel in question through the Turkish Straits, taking into account all specifications of the vessels, including their dimensions and maneuvering capabilities, the morphological and physical structure of the Turkish straits, the condition of the season, the safety of life, property and environment as well as the maritime traffic).
The vessel must notify Turkish authorities at least 72 hours in advance of intention to pass through the Dardanelles Strait.

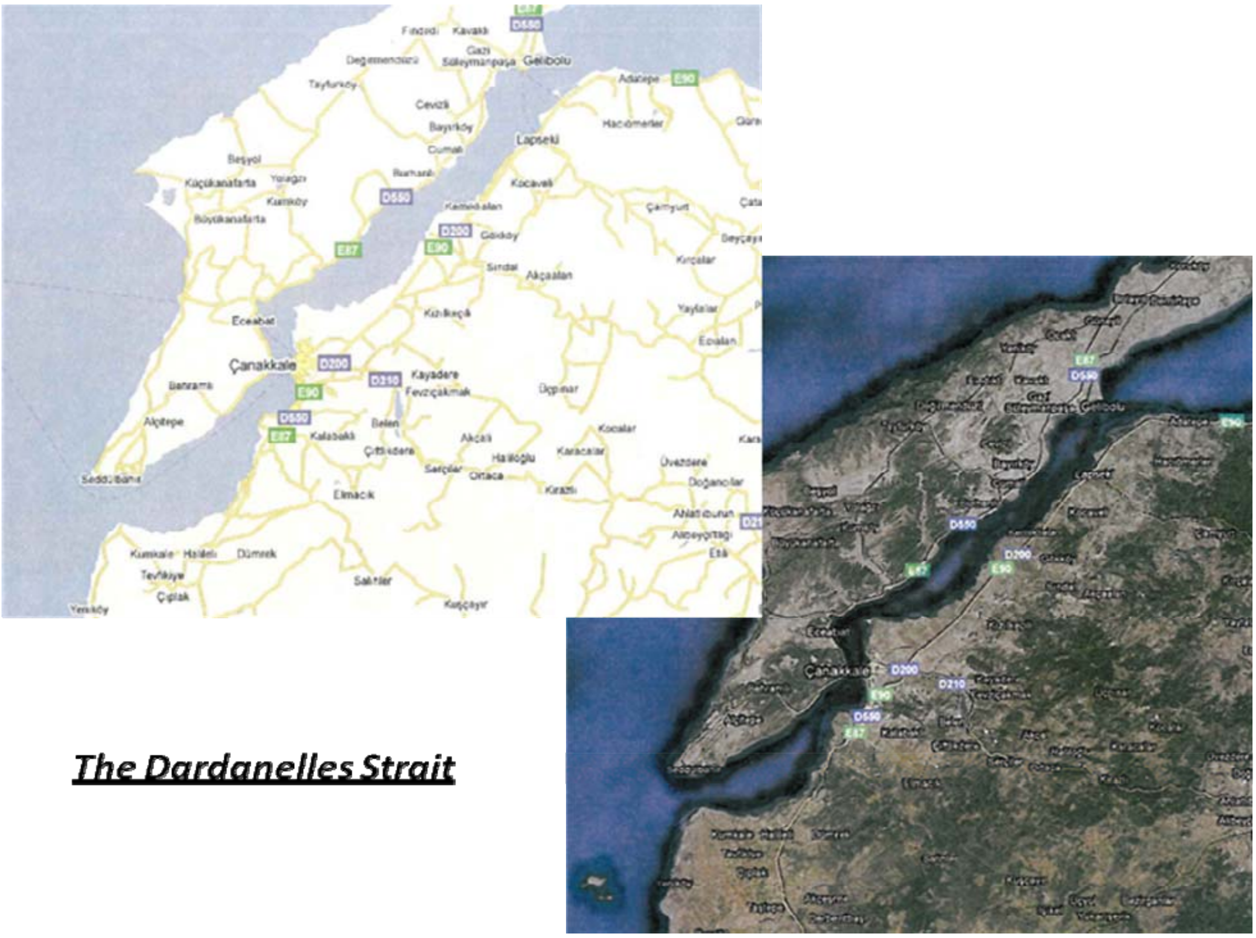


Figure 7.20. Satellite image of the Dardanelles.

(Ref. - http://maps.google.com/maps).

Turkish vessels 150 meters or more in length passing through the Straits shall take a pilot. It is strongly recommended that pilots be used during navigation through the Straits so as to minimize the risk of accidents as much as possible.
WIND AND SEA: Winds from N and NE are most frequent. S winds are usually strong and squally and may sometimes reach to gale force and they are usually accompanied by low cloud and rain when strong, and sometimes by fog when light. The NW winds are usually fresh. They are accompanied by

clear weather. Strong S and SW winds are sometimes dangerous for vessels under loading and discharging.

CURRENTS: When the surface current speed in the strait of Istanbul and ***the Strait of Dardanelles*** exceeds 4 knots or when northerly surface currents are caused by southerly winds, then, vessels carrying dangerous cargo, large vessels and deep draught vessels with a speed of 10 knots or less, will not enter the straits and will wait until the current speeds are 4 knots or less, or the northerly currents have stopped.

(Ref.-
http://www.google.no/imgres?imgurl=http://www.cerrahogullari.com.tr/ports/images/DARDANELLE).

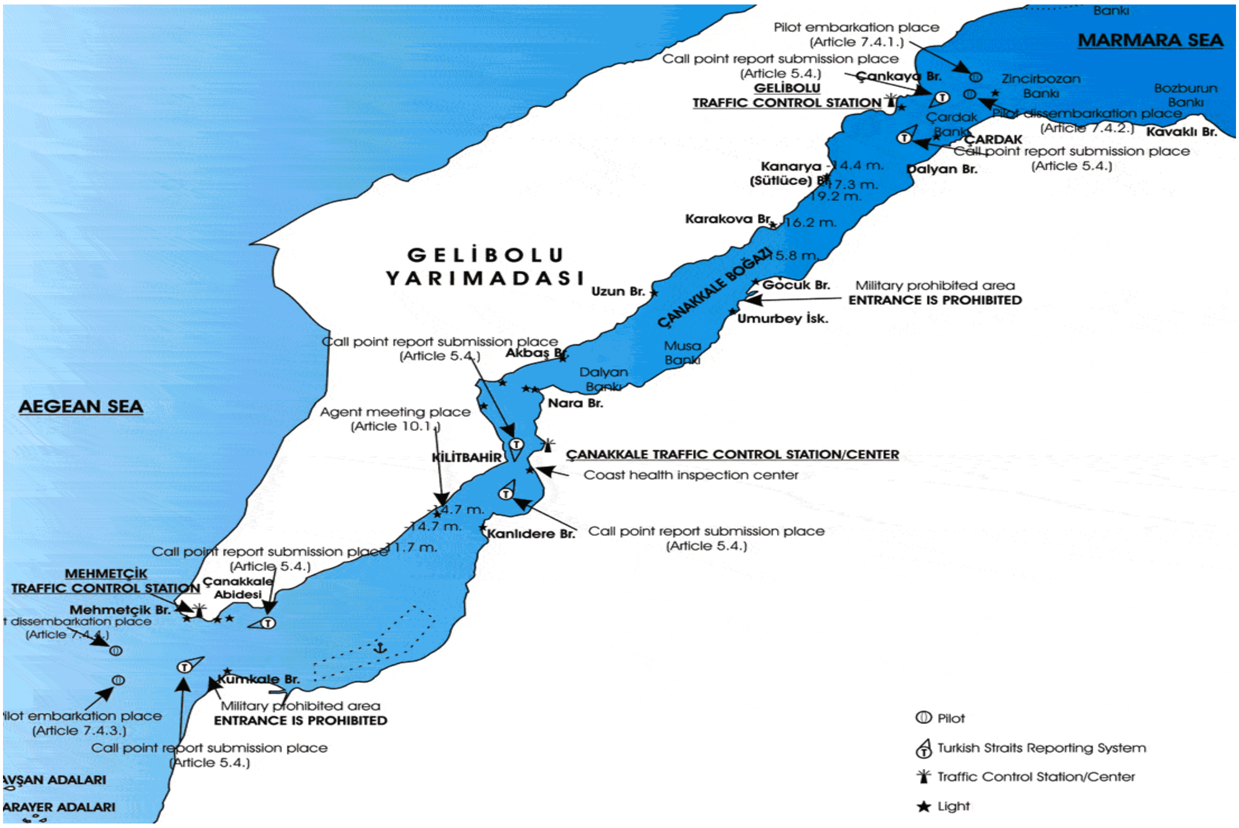


Figure 7.21. The map showing the depth variety of the Dardanelles Strait.

(Ref. -
http://www.google.no/imgres?imgurl=http://www.cerrahogullari.com.tr/ports/images/DARDANELLE).

<u>CONCLUSION:</u> *As we see from the considered material above the Turkish Straits are unique in many respects. The very narrow and winding shapes of the straits are more a kin to that of the river. It is an established fact that the Turkish Straits are one of the most hazardous, crowded, difficult and potentially dangerous, waterways in the world for marines. All the dangers and obstacles characteristic of narrow waterways are present and acute in this critical sea lane. For a catamaran or a trimaran vessel with relatively wide width to pass should not be complicated by geographical and oceanographic features of the given Straits. There are numbers of Rules and Regulations, according to which catamarans/trimarans will be lead safely and properly through these Straits.*

CONCLUSIONS AND FUTURE WORK

This Thesis report has described and presented reasons for and the concept of using multihulls compared with monohulls.

The report has covered information about stability and motions of multihulls by using an example of a catamaran vessel. In the chapter about the "elasto-dynamical theory of multihulls in nonlinear beam seas" an analytical method for design of beams connecting the hulls of multibody system was referred to. The model of a catamaran has been used. As it can be seen from the partial differential equations of the elasto-dynamical theory of multihulls, the elasticity of the beams connecting the hulls has a significant influence on the overall behavior of the multibody system.

The connecting beams are modelled as chains of rigid beams with rotational springs and dashpots in the joints in order to represent stiffness and damping.

The theory is not limited to catamarans. It can easily be applied to trimaran or other multibody system.

Calculations of the water's resistance to the motion of multihulls on still water are dependent on the arrangement of the hulls and by the geometry of the subsea part of the multihull. These factors differently influence on the components of the resistance of such vessels. This is visible from an example calculation of the resistance calculations of a catamaran with a cruiser stern, which are based on input data from model tests (the hulls geometry, the frames shapes, the stern, etc.). After these calculations were made a conclusion that at certain given parameters the speed of the given vessel should not be higher than approx. 22-24 knots (which means the Froude number should be less than 1). Therefore this vessel has to be classified and determined as a high-speed vessel, but it is not applicable for all specified high speed requirements. Trimarans do not offer these limitations.

According to the calculated resistance of high-speed multihulls (a catamaran was used as an example), even by having a number of operational advantages, such as a good cross-section stability, a large deck area and so on, a high-speed *catamaran has some limitations. One of them is the necessity to achieve a glide mode compared with monohulls, to stabilise the multihull.*

By calculations of the resistance of trimaran vessels and by looking on the main advantages of three-hull vessels an opinion was developed that the trimaran can be specified as a vessel with identical or different hulls. Also the advantages of trimarans and catamarans were compared. Trimarans are more stable on a water surface; they are less addicted to the impact from a longitudinal rolling and can get a higher speed, which means higher schedule reliability due to less sensitivity to weather.

This paper has furthermore covered the calculation of the main engine's capacity of a multihull by using an example of the calculation of the propulsive quality of a catamaran. Common types of screw propellers were assumed, such as:

- *free fixed pitch propellers (FPP) or free controllable pitch propellers(CPP)*
- *screw propellers FPP or CPP in a nozzle.*

In this Thesis the possibilities of the fabrication and construction of catamaran and trimaran vessels at shipbuilding plants of Ukraine has also been discussed by showing examples of the capabilities of the shipbuilding plants and their abilities. Also the opportunities of transportation and shipping of the given vessel class from the Black Sea area to the Mediterranean Sea trough the Straits of Bosporus and Dardanelles by using oceanographic and geographic data of these Straits have been discussed.

Future work involves using the strategies and conclusions presented here to fit and adopt the multihull vessels to the North Sea, by using catamarans and trimarans as multipurpose vessels in the offshore industry. These types of the vessels will have great potentials and reasonable advantages over a range of vessels, which are already in use in the North Sea, in particular where it comes to speed, deck space and stability.

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