COMPETITIVE AND SUSTAINABLE GROWTH (GROWTH) PROGRAMME

INNOVATIVE TRANSPORT VEHICLES ON THE DANUBE AND ITS TRIBUTARIES

Working Paper

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0. PREAMBLE

Generally speaking, the main characteristics of all inland (river) vessels are more or less similar. i.e. they have restricted draught (T) due to the restricted water depth (h). However, some rivers are deeper or are regulated and have minimal guaranteed water depth throughout the year, while others are shallower and/or unregulated. The most important European rivers (concerning the SPIN Thematic Network), the Rhine and the Danube, differ mainly in the abovementioned – the Rhine is deeper and regulated while the Danube, although much longer and wider, is relatively shallow and unregulated river with large variations in water depth. Consequently, the main difference between the Rhine vessels and the Danube vessels is just their draught, which has very important consequences on several other ship parameters.

Furthermore, the Rhine passes through the most developed part of the Europe, probably the World, so it is quite normal that several technical solutions applied on the Rhine vessels are copied/transferred to the other river vessels, in this particular case to the Danube vessels. A well known example of the technology transfer applied on the rivers are push trains (a push train technology, instead of towed technology) which are copied from the Mississippi and applied first on the Rhine and then on the Danube. However, it should be noted that often it is not possible to copy/transfer every service or technical solution due to already mentioned waterway differences. Other differences are also important, as for instance industry and infrastructure development along the Rhine and the Danube corridors.

In addition to this, SPIN TN's WG3 Working Paper on *"Innovative Types of Inland Ships and Their Use on the River Rhine, its Tributaries and Adjacent Canals",* written by Prof. Dr. E. Mueller (from now on SPIN-Rhine), was finished and was available before even the work on this "sister paper" concerning the innovative transport vessels for the Danube, started. Therefore, it was decided that only the facts that were not mentioned or are different than those in the SPIN-Rhine WP will be treated here. So, the paper in hands should be considered as an extension to mentioned WP (SPIN-Rhine). Of course, present paper is a stand-alone-paper, but much too often the vessel types, technical solutions, services etc., applied on the so-called "pattern river" Rhine (and therefore mentioned in the SPIN-Rhine) will be cited here too. This was considered important for further understanding and layout of the paper and was, therefore, the main reason for this Preamble.

SPIN's Technical Annex (DoW) for the paper in hands, strictly defines the subject which should be treated here – *Innovative transport vessels for the Danube - which should improve integrity of inland navigation into intermodal transport chains.* Therefore, there are other related topics which are inherently important for design of the Danube transport vessels, as are for instance intermodal transhipment interfaces, intermodal loading units etc. will not be treated here since they are the subject of other working papers within the same WG3 (called Intermodality & Interopereability).

1. INTRODUCTION

Characteristics of transport vehicles – in our case inland vessels for the Danube waterway which should be a link of intermodal transport chain – depend very much on the waterway itself, in the first place its depth, height of the bridges and locks' size. Therefore, main characteristics of the Danube waterway and its tributaries will be given at the very beginning in the Introduction. This will be followed by brief explanations (from a technical point of view) how the water depth influences (inland) ship design. Among others, the purpose of this is to give general impression how the main ship parameters (length, breadth, draught, propeller diameter) of the Danube vessels make them unique and different from, for instance, the Rhine vessels. In the second section, the main characteristics of (future) container and Ro-Ro vessels adapted to the Danube waterway will be given. This is considered as the core of this Working Paper, since container and Ro-Ro vessels are, inherently, a part of intermodal transport chain. In the third section some promising new devices and components important for the innovative Danube vessels will be presented, while other Danube vessels will be treated in the fourth section. Finally, the answers to four particular questions which should be analysed by the WP, among other conclusions, will be given in the fifth section – Concluding Remarks.

1.1 Restrictions of the Danube Waterway (with its Tributaries)

The text which follows, concerning the Danube waterway, is mainly taken from the COVEDA Prefeasibility Study.

1.1.1 The Danube

The river Danube is, according to its physical and geographical characteristics, officially divided by the Danube Commission into three main sectors: Upper Danube (Sector I), Middle Danube (Sector II) and Lower Danube (Sector III). Each of these sectors is subdivided into sections according to different navigational conditions (Table 1). The EUDET Project showed, however, that such division is partly out of date, and proposed a new division of the Danube, which distinct the canalised (articulated) from the free-flowing parts of the waterway. Although the EUDET division relates better to the present state of Danube waterway, there is still not enough statistical analysis (especially concerning water depth) to cover it properly. Even in the EUDET study, the waterway statistics is mostly given according to the Danube Commission classical subdivision.

The most important statistical information, from the point of view of vessel design, is waterway depth and the air clearance under the bridges. So, in Table 2, an attempt was made to re-examine different sources (e. g. EUDET and WESKA), to deduce the appropriate data for water depth at LNRL[*] and critical bridge heights at HWL[**], and to

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[*] LNRL: *Low Navigation and Regulation Level* is the water level that corresponds to the flow available for 94% of duration of the navigable season, i.e. excluding the winter periods of break of navigation affected by ice.

[**] HWL: *High Water Level* is the water level that corresponds to the flow occurring at 1% of duration of the navigable season.

implement them to the EUDET division of the Danube waterway. Numbers in brackets indicate that different data was found in the references.

1.1.2 The Danube Tributaries

The Danube has more than 30 navigable tributaries, but only those having the ECE class III and above are given in Table 3. Since the tributaries have much lower class than the Danube, allowed vessel's dimensions are also depicted in Table 3.

1.2 Basic Approach to Inland Vessel's Hydrodynamics

Fuel consumption depends on power needed for propelling the vessel with a certain speed (neglecting the consumption of generators and probably some other minor consumers on board vessel). Furthermore, different engine emissions (pollution) are also proportional to power installed (if variations which depend on engine type are ignored). Obviously, it is of primary importance to reduce the power needed for moving the ship. This power is called the Brake power (P_B); it depends on vessel's speed (v), resistance (R_T) and efficiency of propulsors (η_D). In particular

$$P_B = R_T \cdot v / \eta_D \cdot \eta_S \,.$$

Now, although this statement may look complicated to the non engineers, elementary discussion of the abovementioned will clearly indicate possible ways for power reduction. In addition, some of the statements which follow will be needed later in the text.

1.2.1 Shallow Water Resistance

The shallow water hydrodynamics is of primary importance for inland vessels and particularly for fast inland vessels. In the shallow water, vessel's resistance is very much different than in the deep water and may play the most important role in inland vessel's design (see Fig. 17 in SPIN-Rhine, for instance). Resistance R_{Th} shows pronounced peak (resistance increases) at critical Froude number (critical speed which depends on water depth). This may be explained with grow, which is then followed by the loss, of transverse waves, see Fig. 18 in SPIN-Rhine. So, although in the abovementioned expression the total resistance R_T was mentioned, in the shallow water only one resistance component – the wave making resistance R_W - changes dramatically (roughly, total resistance R_T consists of viscous resistance R_V and wave making resistance R_W). This phenomenon may be well expressed through the ratio of shallow water wave resistance to deep water wave resistance $r = R_{Wh}/ R_{W\infty}$. Following this logic, three speed regions may be detected:

- **sub-critical** region where the effects of water depth are almost negligible
- **critical** region where R_{Wh} increases dramatically (r is greater than 1)
- **super-critical** region where R_{Wh} may be smaller than $R_{W\infty}$ (r is a bit smaller than 1).

Table 1 Division of the waterway by the Danube Commission

Section	From	Danube km	To	Danube km
Upper Danube – Sector I				
I-1	Kelheim	2415	Passau	2227
I-2	Passau	2227	Linz	2135
I-3	Linz	2135	Vienna	1929
I-4	Vienna	1929	Gonyu	1791
Middle Danube – Sector II				
II-1	Gonyu	1791	Budapest	1646
II-2	Budapest	1646	Moldava Veche	1048
II-3	Moldava Vache	1048	Drobeta	931
Lower Danube – Sector III				
III-1	Drobeta	931	Braila	170
III-2	Braila	170	Sulina	0

Table 2 The EUDET division of the Danube with the main restrictions of the waterway

Section	Danube km	ECE Class	Remark	Depth by LNRL (m)	Air clearance over HWL (m), if lower then 7.5m	Minimal lock dimensions (m) Beam × Length
Kelheim – Straubing	2414 – 2324	Vb VIb	canalised	2.9	6.03	12 × 190
Straubing – Vilshofen	2324 – 2249	VIa	free-flowing (shallow)	2 (1.7)	4.73	
Vilshofen – Melk	2249 – 2038	VIb	canalised	2.8	6.36	2 × 24 × 230
Melk – Durstein	2038 – 2008	VIb	free-flowing (shallow)	2.3 (2.5)	6.65	
Durstein – Vienna	2008 – 1921	VIb	canalised	2.8		2 × 24 × 230
Vienna – Cunovo	1921 – 1853	VIc	free-flowing (shallow)	2.2 (2.5)	6.7	2 × 24 × 230
Cunovo – Palkovicovo	1853 – 1811	VII	canalised	2.5		2 × 34 × 275
Palkovicovo – Budapest	1811 –1646	VII	free-flowing (shallow)	2.0 (2.5)	6.7	
Budapest – Slankamen	1646 – 1215	VII	free-flowing (good)	2.5		
Slankamen – Iron Gates II	1215 – 863	VII	canalised	Well over 2.5		2 × 34 × 310
Iron Gates II – Bala Arm	863 – 346	VII	free-flowing	2.3		
Bala/Borcea Arm – Giurgeni	346 – 240	VIc	free-flowing (good)	2.7		
Giurgeni – Braila	240 – 170	VII	free-flowing	2.4		
Braila – Sulina	170 – 0	VII VIc VIa	maritime section	7.32		
Bala Arm – Cernavoda	346 – 299	VIc	free-flowing (shallow)	Could be bypassed		
Cernavoda – Giurgeni	299 – 240	VII	free-flowing (good)	Over 2.5		
Cernavoda – Constanta	64 – 0	VIc	navigable canal	Well over 2.5		
Chilia Arm – Black Sea	116 – 0	VII	free-flowing (good)	Over 2.5		

Table 3 Navigable tributaries and canals of the Danube

Tributary	Section of the waterway	ECE Class	Allowed vessel's dimensions Width (m)	Draught (m)	Height (m)	No. of locks	Locking time (min)	Remark
MD Canal	Bamberg - Kehlheim	Vb	11,4	2,7	6	16	20	-
Drava	km 68 – Osijek	III	8,2	1,9	4	-	-	-
	Osijek – Danube	IV	9,5	2,5	5,3	-	-	
Tisa	Tisa - Danube	IV	9,5	2,5	-	3	20	Stable nautical conditions
Sava	Sisak – Sabac	III	8,2	2	4	-	-	Local shallows
	Sabac – Belgrade	Va	11,4	2,5	-	-	-	Local shallows
DTD Canal	Bogojevo - Becej	IV	11	2,5	6,2	3	20	-
	Becej – Palanka	IV	11	2,5	5,6	3	20	Link to Tisa from lower Danube
Tamis	Danube – Pancevo	IV	-	2,5	-	-	-	Up to Port of Pancevo
Begej	Tisa – km 35	IV	11	2,5	5,6	1	20	-
	km 35 - km 64	III	9,5	2	5,4	2	20	-
D – Black Sea Canal		VI b	22,8	5,5	17	2	30	Acces to the Port of Constantza
White Gate – Midia Canal		Va	11,4	3,8	13,5	2	20	Acces to the Seaport of Midia

The increase of wave-making resistance – resistance ratio r - in the critical region is of primary importance for the fast vessels and depends mainly on the ratio of L/h (where L is vessel's waterline length). This is well depicted by a 3D diagram given in Fig. 1.1 (Hofman and Radojcic 1997, Hofman and Kozarski 2000), where $F_{nL} = v/\sqrt{(g \cdot L)}$ is Froude number based on ship waterline length. Similarly, the so called shallow water resistance charts, shown in Fig. 1.2 and 1.3, indicate by gray scaling the critical region – black and dark-gray zones should be avoided. In Figure 1.3, $F_{nh} = v/\sqrt{(g \cdot h)}$ is the depth Froude number (relation between two Froude numbers is $F_{nh} = F_{nL}\sqrt{(h/L)}$). All three diagrams are obtained by relatively complicated theoretical calculations, nevertheless the diagrams shown are universal, simple and therefore useful since the influential parameters that are tied together are only L, h and v – the other ship parameters (ship form and dimensions) are practically not important and may be neglected.

Furthermore, according to (Hofman and Radojcic 1997) the only way to avoid the critical region (negative influence of water depth) is to avoid the critical region itself, i.e. the speed corresponding to $F_{nh} \approx 0.9\text{-}1.0$, $F_{nL} \approx 0.3\text{-}0.4$ and low values of h/L. This means that good inland vessels, particularly the fast ones, should be designed according to the water depth h, or in broader sense, according to the particular waterway. Consequently, the right choice of vessel's speed and waterline length should be decided in the very early design phases, since there isn't any possibility to improve the poor performances later on (this is not the case with the deep water sea going vessels).

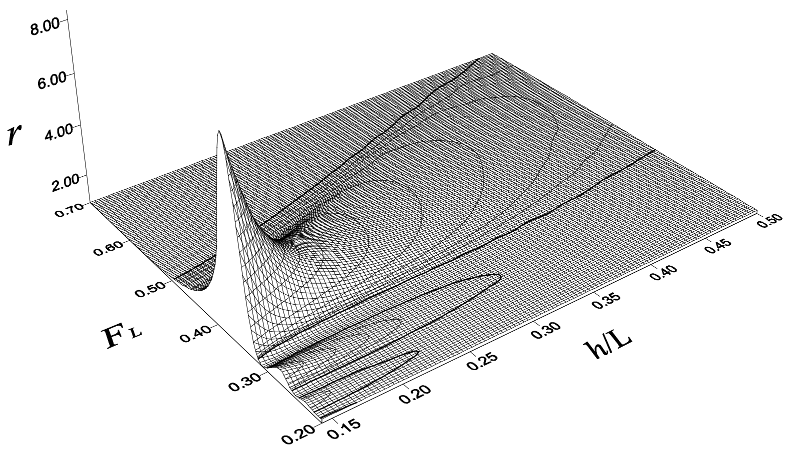

Fig 1.1 Shallow water resistance ratio

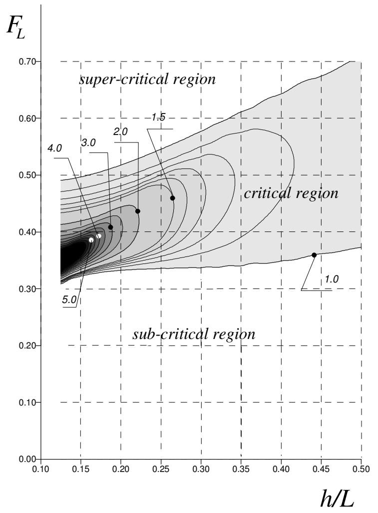

Fig. 1.2 Shallow water resistance chart

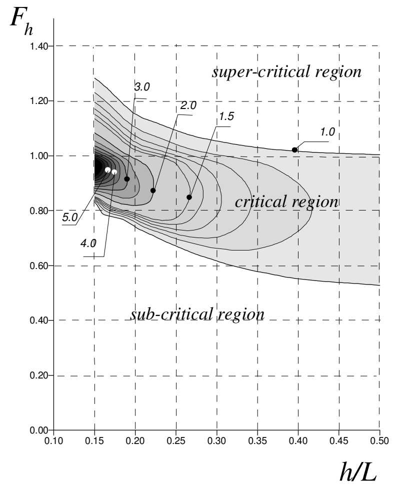

Fig. 1.3 Shallow water resistance chart

1.2.2 Propulsive Efficiency in the Shallow Water

The denominator in the above equation ($\eta_D \cdot \eta_S$) is called the total propulsive efficiency, but since η_S is around 0.95 (i.e. transmission losses are 5%) regardless of water depth, only η_D is of further interest (η_D is the propulsive efficiency, also called quasi propulsive efficiency). Propulsive efficiency changes in shallow water exactly opposite to the resistance, i.e. around the critical Froude number η_D decreases compared to the value in deep water (curve η_D as a f(F_{nh}) has pronounced hollow around the critical speed, specifically around $F_{nh} \approx 0.9$). This hollow (η_D reduction), among other reasons, is explained by increased propeller loading due to increased resistance in shallow water (Hofman and Radojcic 1997, Radojcic 1998). So, if there is not enough space for placing a sufficiently large propeller, which is the usual case, increased propeller loading in addition to already mentioned lower performances, may be followed by erosive cavitation.

1.2.3 Wash Problems

High speed vessels generate large waves (followed by increase of wave making resistance), which may cause environmental problems (bank erosion) and endanger other users of the waterway. Waves generated by forward motion of a ship are called wave-wake or just wake. The main wake (wash) problem is associated with the passage through a critical speed range and is particularly pronounced in the shallow waters. Of course, this is an additional reason why critical and even near critical speeds should be avoided.

1.2.4 Concluding Remarks Concerning the Shallow Water Hydrodynamics

- Inland (shallow water) vessel should be designed (matched) according to the waterway's characteristics, i.e. vessels main parameters (draught, length, propeller size etc.) should be adjusted to the specific waterway.
- In the shallow water, three characteristic regimes exist:
    - Sub-critical (according to ITTC bellow F_{nh}=0.7)
    - Critical, where P_B increases dramatically due to increased resistance and decreased propulsive efficiency
    - Super-critical, where P_B may be smaller than in deep water due to smaller resistance and somewhat larger propulsive efficiency.
- By far most inland vessels sail in the sub-critical regime. Only some special, very fast, inland vessels are capable of reaching the super-critical regime (in that case, they should pass through the critical regime as fast as possible due to enormous increase of demanded power).
- The regime borders (and appropriate speeds) depend on the water depth h, which varies from one river/river sector to another river/river sector. Consequently, subcritical/critical/supercritical speed range is different, for instance, for the Rhine and the Danube or for Upper and Middle Danube.
- High speed vessels generate large wake (wash) which may cause serious bank erosion. So, the critical and near-critical speeds should be avoided due to the environmental reasons as well.

2. INTERMODAL VESSELS FOR THE DANUBE WATERWAY

Although the Danube waterway is a part of a major transport corridor connecting Central Europe's main economic regions to Western Europe and to Black Sea Region, the traffic on the waterway is, presently, at a very low level. Its utilisation is 7-10% of its full capacity only (Muilerman et al. 2003). That is the consequence of numerous economic and political reasons that are beyond the scope of the present WP, but also of the currently improper navigational conditions on the waterway itself. In addition to this, the Danube fleet, in general, is old and is in terrible shape; in last twenty or so years there were only few newbuildings operating on the Danube. Of course, these are not the only reasons why the intermodal transport almost does not exist on the Danube.

On the other side, the objective of the SPIN TN and particularly of WG3 is to help the increase of inland navigation, specially of intermodal transport. Therefore, brief results of the COVEDA and MUTAND studies will be presented in this chapter since they practically treat the future – innovative - container and Ro-Ro vessels.

2.1 Container Vessels for the Danube Waterway

The problems connected to the design, construction, hydrodynamics, stability, etc. of inland container vessel are very different from those of sea going ships. Already mentioned restrictions in draught connected to waterway depth, restrictions in air draught connected to the height of bridges, restrictions in beam and length connected to the size of locks, make numerous and serious challenges to the designer. A good inland container vessel therefore, differs significantly not only from the sea going ship, but also from one waterway to another. An optimal Danube container vessel would certainly not be the same as the optimal vessel for the Rhine or some other waterway.

Section which follows starts with the present situation, and then brief results from the COVEDA study will be presented. In the COVEDA study the guidelines for design of innovative Danube container vessels are given.

2.1.1 Container Vessels on the Danube – Present Situation

Probably the most successful general cargo and (when without hatch covers) container selfpropelled vessels on the Danube are of a class MGSS "Jochenstein" (Fig. 2.1) built in Osterreichische Schiffswerften AG in Linz-Korneuberg, for German (about 10 vessels) and Soviet, now Ukrainian (about 15 vessels), shipping companies. Their main characteristics follow:

Loa = 95 m
Boa = 11.4 m (some of them 11.0 m)
H = 3.2 m
T = 2.7 m
Highest fixed point 6.5 m above basis line
Cargo capacity 1960 t

P_B = 2 x 600 kW (some of them 2 x 800 kW)
Bow thruster 130 kW.

MGSS "Jochenstein", although built twenty years ago, was a prototype for probably the only newly built selfpropelled vessel on the Danube (still not finished). JRB's selfpropelled ship is shown in Fig. 2.2. Presumably unusual, but JRB chose the old Danube standard for breadth (11 m), so as a container vessel she will be able to carry only three containers abreast (instead of four with B=11.4 m).

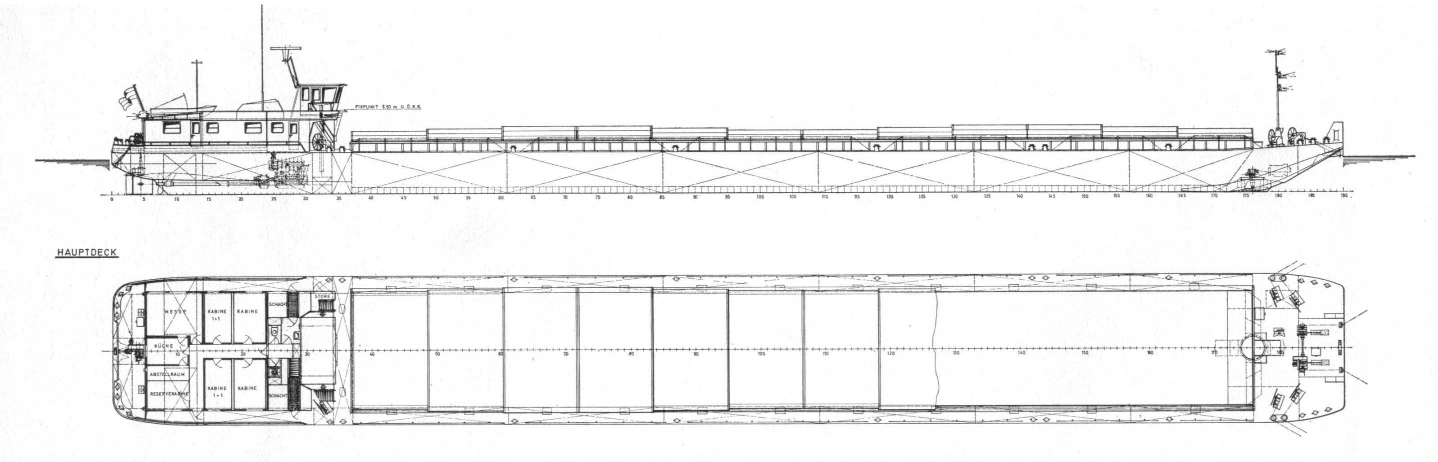

Fig. 2.1 General Arrangement MGSS Jochenstein"

Fig. 2.2 JRB Newbuilding No. 1188

2.1.2 Maximal Vessel Dimensions

The impact of restrictions of the Danube waterway (see Tables 1 and 2) on vessel main dimensions could be summarised in the following.

- **Vessel draught** is restricted by water depth. The clearance between vessel and waterway bottom should be, at least, 0.2 m – 0.4 m. As the depth of the river is highly changeable at one location during the season, as well as along the waterway, the proper assessment of design draught from the given statistical data is a crucial, but also a very delicate and complex matter. The choice of draught is influenced by not only the statistics of waterway depth, but also by available cargo and other transportation and financial reasons, risks, technical characteristics of the vessel, etc. However, technically reasonable starting value for maximal draught of Danube container vessel is assessed to 2.5 m, which is equal to LNRL on the most of the waterway downstream Passau. Although it is a high value compared to the existing Danube vessels, it could be deduced from the statistical data given in the EUDET study, that such vessel would be able to sail between Passau and Iron Gates approximately half of the season, and (perhaps) a bit less between Iron Gates and the river mouth. The rest of the season, the vessel would have to be lightened, to reduce the draught. The vessel would also have to reduce the draught if sailing up of Passau. Therefore, in the text to follow (which concerns the container vessels), not only the maximal draught of T = 2.5 m will be considered, but also two possible alternatives: vessel of medium draught T = 2.1 m, and vessel of small draught T = 1.7 m.

  Even more complex then the draught consideration is the choice of the proper propeller diameter. Although that problem will be discussed later, it should be noted that, in contrast to the draught (which could be reduced by smaller cargo weight) once chosen diameter could not be changed. It follows, logically, that propeller should be designed according to the minimal draught requirements. Such choice implies, however, a possible reduction of its efficiency.

- **Vessel beam** is restricted by the size of locks. Vessel in a lock should have, at least, 0.3 m side clearance. So, vessel maximum beam is:

  Practically unrestricted by waterway downstream of Vilshofen,
  Restricted to 23.4 m downstream of Reggensburg,
  Restricted to 11.4 m upstream of Reggensburg.

- **Vessel length** is restricted by the size of locks and by waterway bends. These restrictions are well above the values implied by the technical logic, so the length (of selfpropelled vessel) should not be considered restricted by the waterway (for push convoys, see the ECE class, Table 2 and Fig. 12 of SPIN-Rhine).

- **Vessel air draught** is restricted by the height of bridges above the water level, which is random and highly changeable. Although a similar reasoning applies to air draught as to water draught, the problem seems simpler, as vessel's air draught changes discontinuously with the number of container layers. The data for the height of the bridges in Table 2 is given for the extremely high waters (HWL), so it is technically reasonable to adopt a bit larger values for maximal air draught. We choose, for a start, air draught of e.g. 6.5 – 9 m, depending on the vessel route, leaving the details for later analysis. Such vessel would not be able to pass all the Danube bridges at HWL, but would be able to sail fully loaded for most of the season.

From the above reasoning, the following restrictions of Danube selfpropelled container vessels are considered:

- Vessel for routes downstream of Passau, with maximal **draught 2.5 m**, unrestricted by the waterway in beam and length.
- Vessel for whole Danube route, able to operate up to Kehlheim and join the Western waterways through the Danube – Main Canal, with maximal **draught 1.7 m**, maximal **beam 11.45 m**, unrestricted in length. The air draught of these vessels would be discussed in connection to number of container layers onboard.

2.1.3 Number of Containers

The number of containers abreast on inland vessels varies from three to six. There seems to be no reason to go out of these limitations on the Danube waterway. So, the properly chosen beams of container vessels should change discontinuously in the following manner:

$B \approx 9$ m , for 3 containers abreast,
$B = 11.4$ m , for 4 containers abreast,
$B \approx 14$ m , for 5 containers abreast and
$B \approx 16.5$ m, for 6 containers abreast.

In the case of four containers abreast, the beam should not precede 11.4 m, so the vessel could pass the 12 *m* locks on the upper Danube. Actually, the beam of 11.4 *m* is a good measure not only from the point of view of container load, but also from the point of view of 12 *m* locks. Therefore, it became practically a standard for the Rhine vessels. It will be, however, less significant for the lower Danube container vessels, as their beam is practically unlimited by the locks. Consequently, the number of TEU containers to vessel main dimensions is depicted in Fig. 2.3.

Choice of length and beam from these diagrams is straight forward, except for the regions where the lines overlap. In these overlapping regions, the designer has to decide between two vessel concepts with very different ratio *L/B*. This decision depends on numerous stability, resistance, propulsion and strength considerations. It is a challenging topic, analysed separately, under the title 2.1.8 Long or Beamy Vessel.

2.1.4 Average Mass of Containers

Average mass of containers changes randomly from trip to trip. However some proper, long-term average value has to be assessed. It was shown that the proper choice for the Danube container vessel is close to 13 t. This mass is called the **required container mass**.

For the seagoing container ships of unrestricted draught, it is generally not difficult to obtain the required (good) average container mass when the ship is fully loaded by her weight and volume. Such ships have proper relation between cargo space and cargo weight - they are **well balanced**.

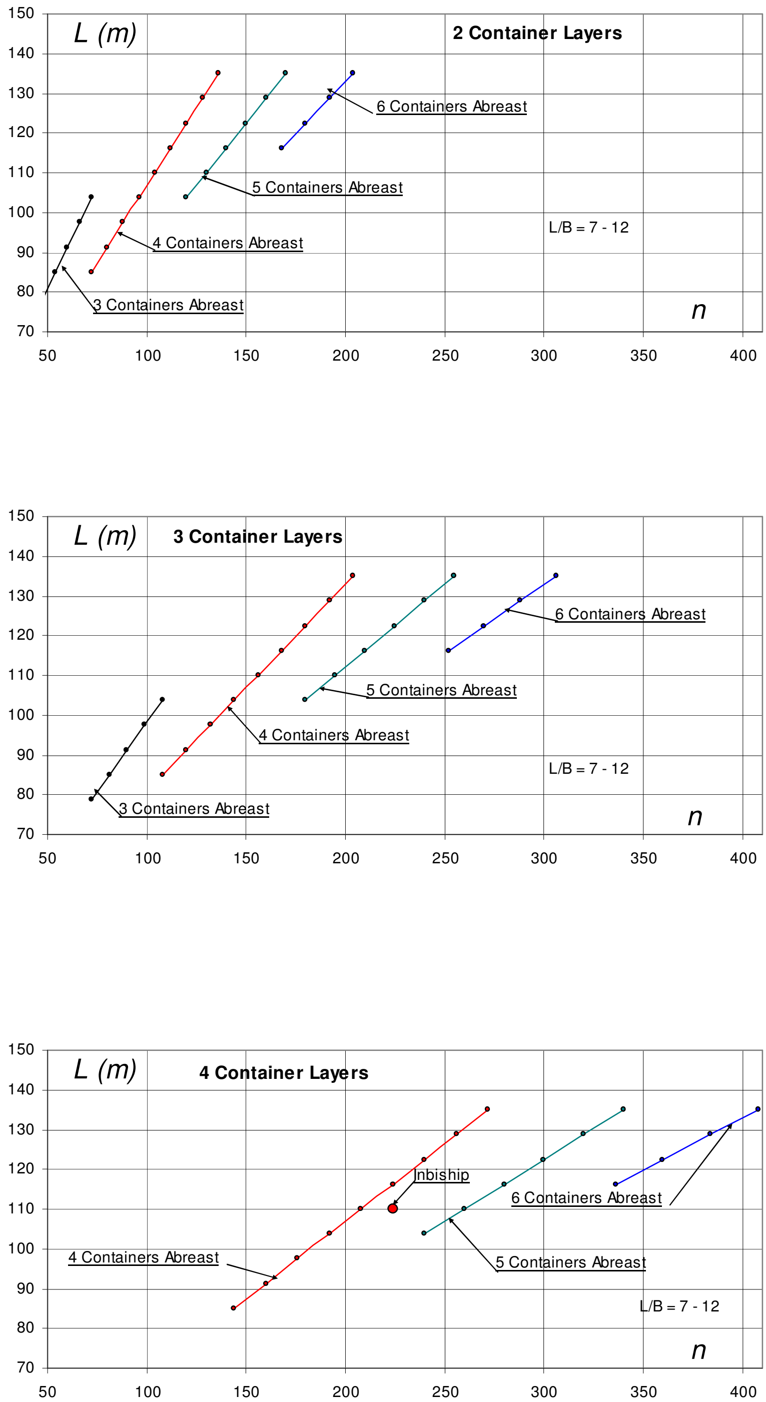

Fig. 2.3 Relation of vessel length to number of TEU containers

The average available container mass of containers for the inland vessel is limited and is in direct correlation to its restricted draught. Consequently, it is a challenging task to achieve an inland container vessel to be well balanced.

The problem of proper balancing of the Danube container vessel is analysed in detail. It was found that the main impact on the available container mass m_c is draught T and number of container layers n_H, while the other parameters are of secondary importance. The results presented in Fig. 2.4 show that only a certain combination of T and n_H imply a well-balanced vessel having $m_c \approx 13t$.

The inverse problem was also studied, the draughts that would give the required container mass of *13 t* were obtained. Such “proper draughts”, as presented in Fig. 2.5, should be between 3 – 3.25 m for the four-layer vessel, as is usual on the Rhine. For the three-layer vessels the proper draughts are between 2.25 – 2.5 m, while for the two-layer vessels follows 1.6 – 1.85 m.

The problem of insufficient container mass while draught is limited, turn to be very specific for the inland container vessels. It was shown that the only way to increase available container mass (without decreasing the number of containers or increasing draught) is to reduce the lightship weight.

2.1.5 Hull Weight Considerations

The problem of insufficient container mass emphasized the demand for low hull structure weight. Generally, this goal could be accomplished in two ways – by optimizing the hull structure, or by the use of high tensile materials, see Section 3.1.2.

2.1.6 Stability Considerations

It is well known that the stability requirements limit the number of container layers onboard the seagoing container ships. Therefore, these ships are usually designed with very small stability margin, achieved often by an uneven vertical load distribution; so, the heavier containers have to be in the lower layers.

The number of container layers onboard inland container vessels is, on the other hand, limited by the maximal air draught. Present study shows that in all technically realistic circumstances the transversal stability of the Danube container vessels would be sufficient. The only exception to this rule is a narrow vessel with 3 containers abreast, carrying 4 container layers, where stability could only be achieved by an uneven vertical load distribution.

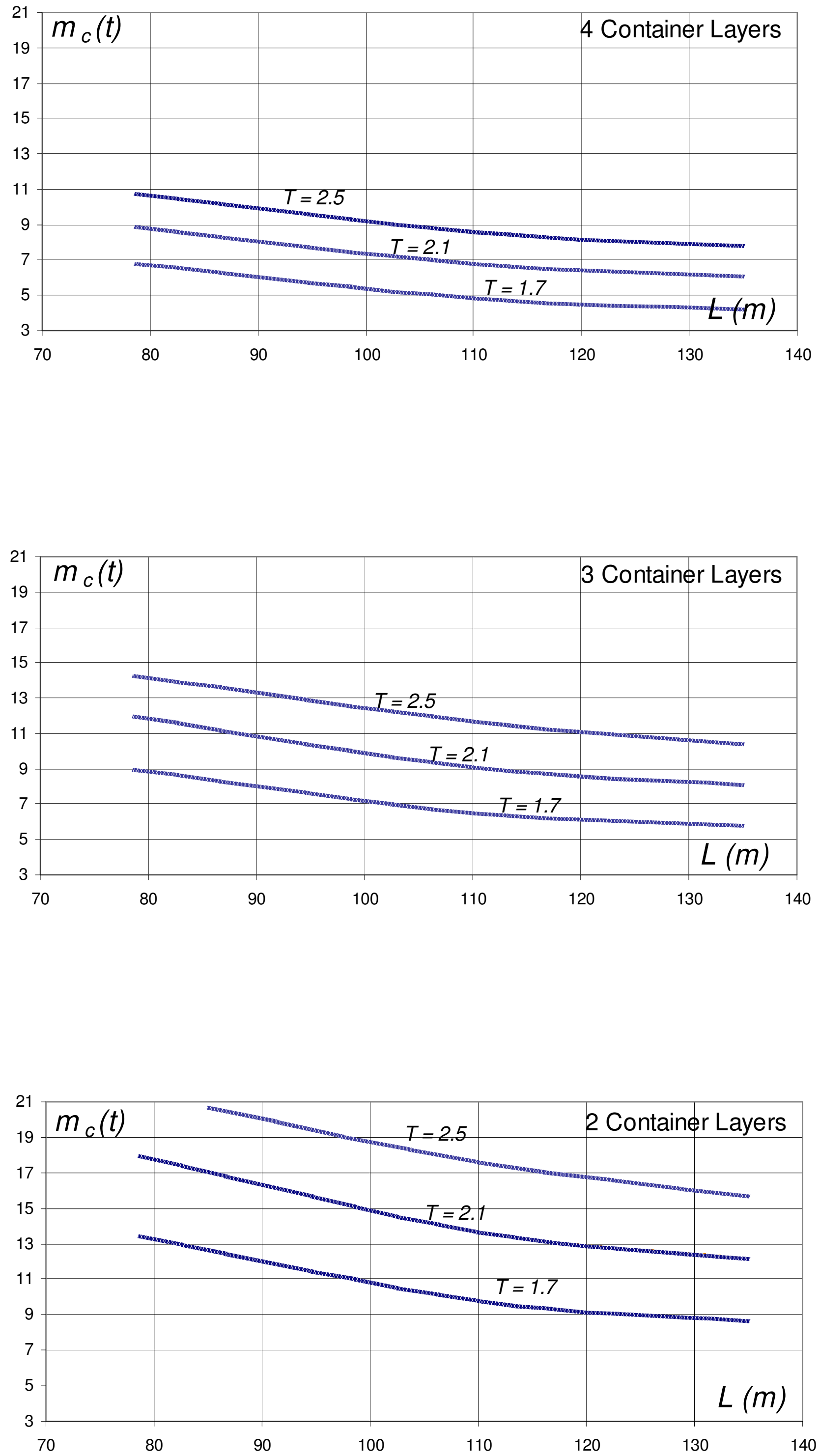

Fig. 2.4 Average available mass of containers

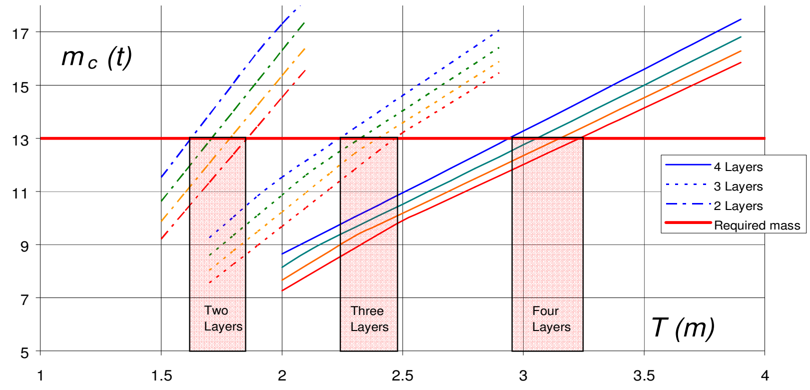

Fig. 2.5 Proper draughts for two, three and four layer container vessels.

2.1.7 Transport Economy and Hydrodynamic Analysis

An attempt was made to study transport economy from the hydrodynamic point of view. Various coefficients of transport efficiency were analysed (their dependence on hull form, main dimensions, propeller diameter and some other vessel characteristics). Consequently, the result of a newly introduced coefficient of container transport efficiency

$$C_C = \frac{n \cdot v}{P_B} \left[\frac{no.\,containers \cdot km/h}{kW} \right]$$

as a function of vessel length and beam are shown in Fig. 2.6 It shows that the efficiency is increased mostly by adding a layer of containers, but also by removing a row of containers abreast. The large container vessels with 5 or 6 containers abreast never reach the efficiency of the less beamy vessels. So (somewhat unexpectedly), smaller vessels, in this sense, are found to be advantageous.

The influence of propeller diameter on the transport efficiency (Fig. 2.7) also gives an unexpected result. Although (as expected) the efficiency increases with the increase of the propeller diameter, the influence is relatively small. Taking into account all the risks connected with large propeller diameters, it follows that smaller propellers could be advantageous. This conclusion is reconsidered in more detail by analyzing propulsive efficiency η_D . The results are presented in form of 3D diagrams (Fig. 2.8) showing also the minimal diameter due to the cavitation criterion. The abovementioned considerations are based on a propeller in a nozzle. If naked propellers would be used it might be expected that the propulsive efficiency η_D would be around 5% less.

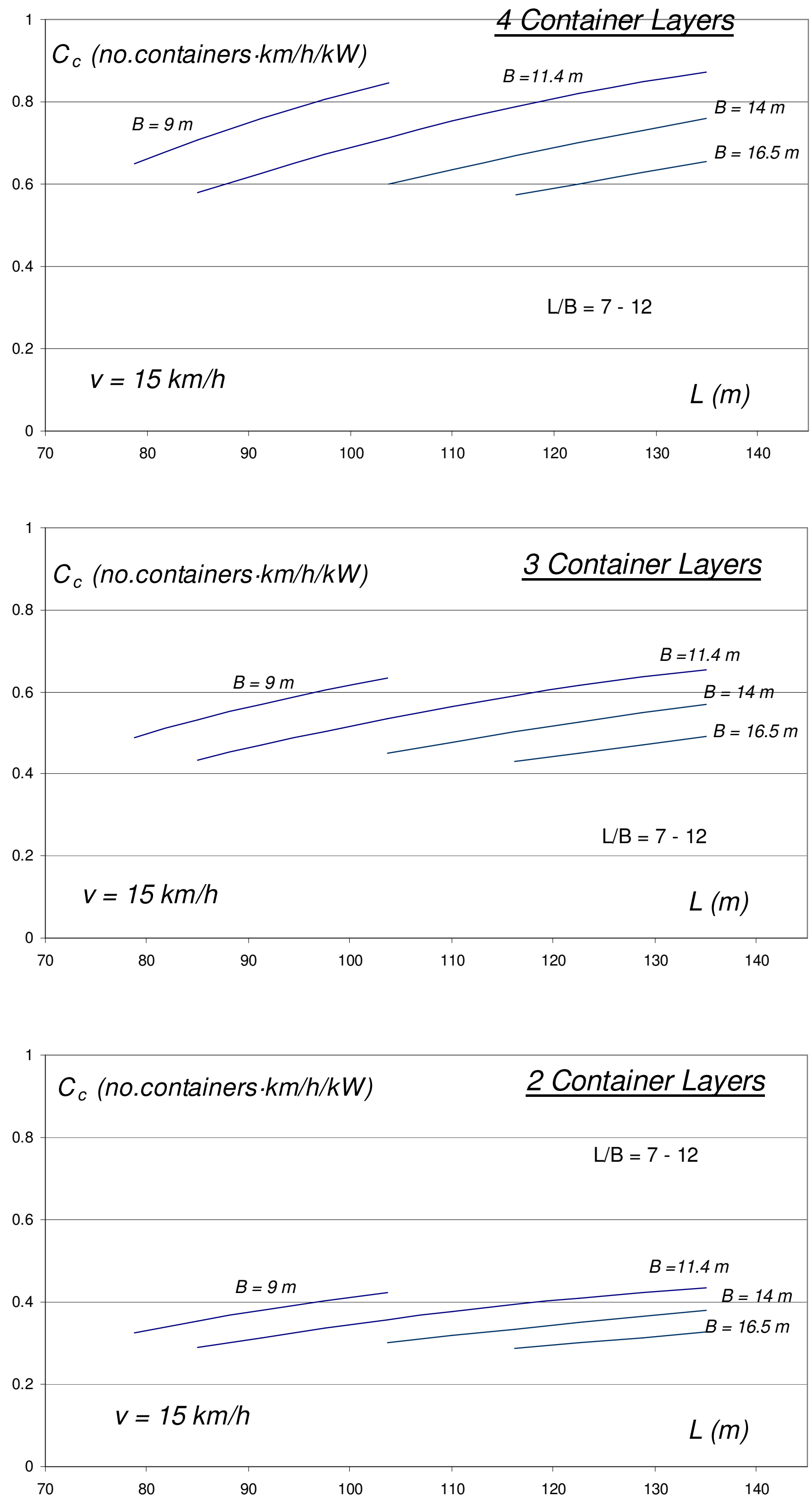

Fig. 2.6 Coefficient of container transport efficiency C_C for different L and B.

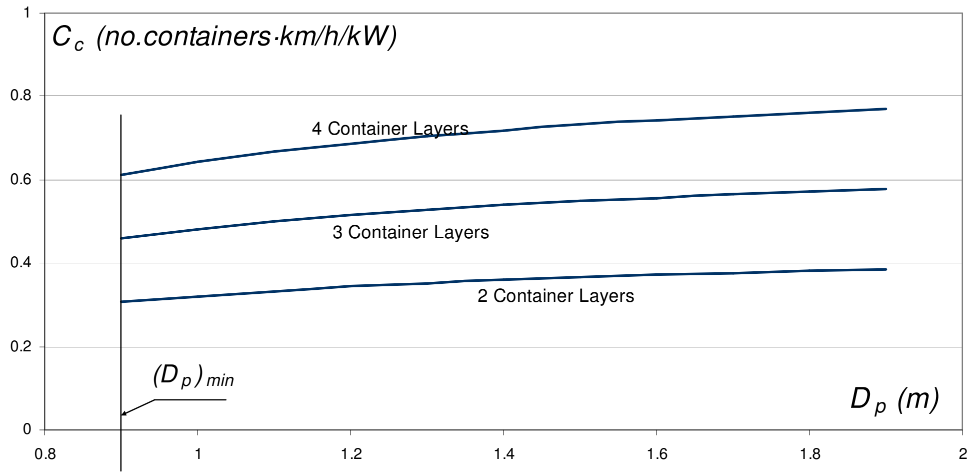

Fig. 2.7 Coefficient of container transport efficiency C_C for different propeller diameter

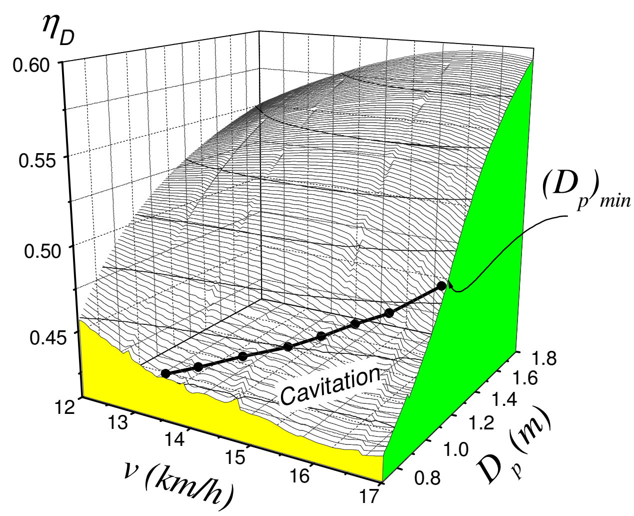

Fig. 2.8 Propulsive efficiency η_D as function of speed and propeller diameter

2.1.8 Long or Beamy Vessel

For a given number of containers and container layers, the choice of vessel length and beam is straight forward. However, as mentioned earlier, for certain number of containers there is an overlapping, so two very different choices could be made: one with $L/B = 10-12$, and the other with $L/B = 7-9$. As both vessels would have the same draught (e. g. 2.5 m), we may name them the "long" and the "beamy" vessel, respectively. The question is: which of alternatives to chose?

It is known, theoretically, that the long vessel should be advantageous from the wave-resistance point of view, while the beamy vessel would be beneficial in stability and hull-weight considerations. Looking at the concrete numbers, however, we conclude that stability requirements would be satisfied for the beamy and for the long vessels. So, the compromise should be made just between resistance and the weight considerations.

As explained, the reduction in hull weight is found more significant for the inland container vessels then for the usual seagoing ships, because of their limited draught. Only if the hull is light enough, the vessel could load the containers of the required mass, and be well balanced. The importance of this weight requirement emphasizes the advantage of the beamy vessel. The rough analysis indicates that the reduction of hull weight by choice of beamy instead of long vessel (in the case of three container layers) is approximately 10 -15%. This gives the increase of available container mass of approximately 5 - 10%. Could this beneficial effect balance the increase of resistance?

The wave resistance in shallow water (see section 1.2.1) depends mainly on parameters L/h and L/B, and both of these parameters are reduced if the beamy vessel is chosen instead of the long one. The reduction of L/h would be beneficial, but only if the resistance is influenced by waterway bed. This is the case for high, near-critical speeds. However, these speeds are well above the economic limitation for the container vessels. So the resistance is influenced mainly by the change of the parameter L/B. Its decrease, by the change from the long to the beamy vessel, significantly increases the wave resistance.

The increase of wave resistance is followed by the decrease of transport efficiency, as is shown in Fig. 2.6. By choosing the long instead of beamy ship, the coefficient of container transport efficiency could increase up to 20%. Is such a jump large enough to compensate the opposing increase of hull weight? The latest trends on the Rhine seem to be in favor of that, as they show the tendency towards the vessels having $L/B > 11$, which was the traditional limitation of the Classification Rules.

Concerning the selfpropelled container vessels for the Danube tributaries, it follows from the previous discussion and Table 3, that smaller vessels of $B \approx 9$ m (three containers abreast) with two container layers (sometimes three) would be adequate. Consequently, if the vessel's length is 80 m (allowed by ECE class IV) than according to Fig. 2.3, carrying capacity would be around 50 to 75 TEU containers, for two and three container layers respectively.

2.1.9 Analysis of vessel powering characteristics

Analysing vessel characteristics (such as propeller diameter, propulsive efficiency etc) and some newly introduced parameters (coefficients of transport and container transport efficiency) some unexpected results were obtained, as for instance the advantage of smaller, long and narrow vessels, over the large, beamy ones. Also, relatively insignificant influence of screw diameter on the overall efficiency, indicating the advantages of smaller propellers is shown. Reduced power demands also reduce the pollution generated by main engines, so the analysis performed is important from the environmental point of view too.

2.2 Ro-Ro Vessels for the Danube Waterway

As mentioned in the Preamble, the objectives of this WP are not the loading units or transshipment equipment. However, in the particular case of Ro-Ro vessels these have to be mentioned. Namely, the main advantage of the Ro-Ro vessels compared to the just treated container vessels is simple and fast (and therefore cheap) loading and unloading of cargo from shore to ship and vice versa. This is done horizontally via bow/stern/side ramps by the vehicles which inherently have wheels (abbreviation Ro-Ro actually stands for Roll-on Roll-off). The term Ro-Ro[1)], however, was gradually modified and nowadays is applied to vessels carrying on board road vehicles loaded with their own cargo - trucks and trailers/semi-trailers (see MUTAND Project). This is opposite to, for instance, loading/unloading of containers done vertically (hence the abbreviation Lo-Lo stands for Load-on Load-off) by some kind of a ship or shore crane. Specialised (efficient) cranes – gantry cranes - are expensive and are used when a large number of container units should be transshipped (large ports, hubs).

Nevertheless, if we disregard the transshipment, waterborne transportation of containers is much more efficient since containers are stackable, while the loading units which are used on the Ro-Ro vessels – usually trucks or trailers – are obviously not stackable. In other words, Ro-Ro vessels can compete with the other intermodal vessels (container ships) only if complete transport chain, and definitely with the transshipment process, is taken into account. Otherwise, if only waterborne segment of transport chain is examined, than Ro-Ro vessels are absolutely inefficient water-transport vehicles.

Few generations of sea Ro-Ro vessels developed during last 20-30 years are the best evidence that Ro-Ro vessels might be very profitable and efficient intermodal transport vehicles. Furthermore, inland (river) Ro-Ro vessels are rare and the transport chain

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[1)] According to MUTAND Prefeasibility study - "The ships designed and involved in transportation (In the field of inland navigation) of new manufactured road vehicles (usually passenger cars, but also trucks, tractors, fork lift trucks or any other devices which are mobile on their own rolling undercarriage assembly) are properly classified as special ships, or more precisely ships for special transports. The same classification is assigned to ships having all design particulars as the real inland Ro-Ro ships, but whose prevailing role is sporadic waterborne transport of extremely heavy and voluminous single piece cargoes like large boilers, reactors, transformers etc. - where other land based modes are not able to provide competitive long distance service. Even the vessels used for permanent service in real multimodal transport chains, but on very short distances (just for transport of road cargo and passenger vehicles across the river), are called simply "ferries", and in no case "Ro-Ro" vessels. Therefore, the vessels which are specially designed, built and equipped for horizontal reloading procedures of road cargo vehicles and their regular transport, loaded or unloaded with their own cargo (but in any case on the considerable part of the route within their transport origins and destinations) between two points along the inland waterway, can be classified as inland Ro-Ro ships. Thus, the meaning of the term Ro-Ro in inland navigation is rather a matter of modality of transport than particulars in ship design".

which involves river Ro-Ro vessels has some peculiarities which will be discussed in the text that follows.

2.2.1 River Ro-Ro transport

Inland (river) transportation may be replaced by some other mode, for instance railway or road (what is not the case with the sea transport which often cannot be replaced by any other mode). Consequently, if Ro-Ro vessels (and Ro-Ro service) are not efficient enough, transport users (truck operators and forwarders) will avoid them and will use roads or probably Ro-La trains (abbreviation for Road-Rail combined transport). For instance, along the corridor of the "pattern" river Rhine a well developed transport infrastructure exists (both, roadway and railway), transport distances are relatively short etc., so Ro-Ro transport practically never started (not counting transport of new passenger cars, special cargo etc.).

Few studies (EUDET, MUTAND etc.) revealed that the Danube is actually a very convenient river for Ro-Ro transportation since:

a) the transport routes are long (approximately 500 km is necessary for efficient operation of a Ro-Ro line)
b) the corridor lacks sufficiently developed roadway/railway infrastructure.

In addition, the riparian states, much less developed than those along the Rhine, do not have a "habit of using" containers, not to mention necessary logistical support (see Fig. 2.9).

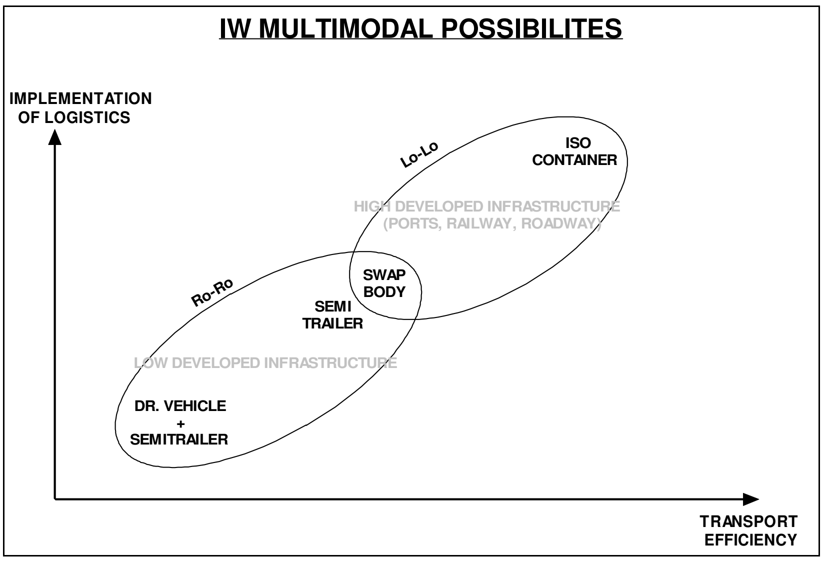


Fig. 2.9 Inland waterway multimodal possibilities

2.2.2 Ro-Ro Transport on the Danube (from MUTAND Prefeasibility Study)

The regular Ro-Ro transports on the Danube began in June 1982. The Bulgarian SOMAT transported road trailers on board the Ro-Ro semi-catamaran "Han Asparuh" from the terminal in Passau/Schalding to the Bulgarian Port of Vidin. A total of four ships have been built and delivered in 1982 and 1983. Two vessels of this semi-catamaran underwater form named "Han Asparuh" and "Han Tervel" have been built in "Deggendorfer Werft und Eisenbau GmbH" in Deggendorf (Fig. 2.10), while the other two units of full catamaran hull form named “Han Kardam” and “Han Krum”, with slightly changed design - but in general with the same particulars - were delivered from Danubian yards in Serbia.

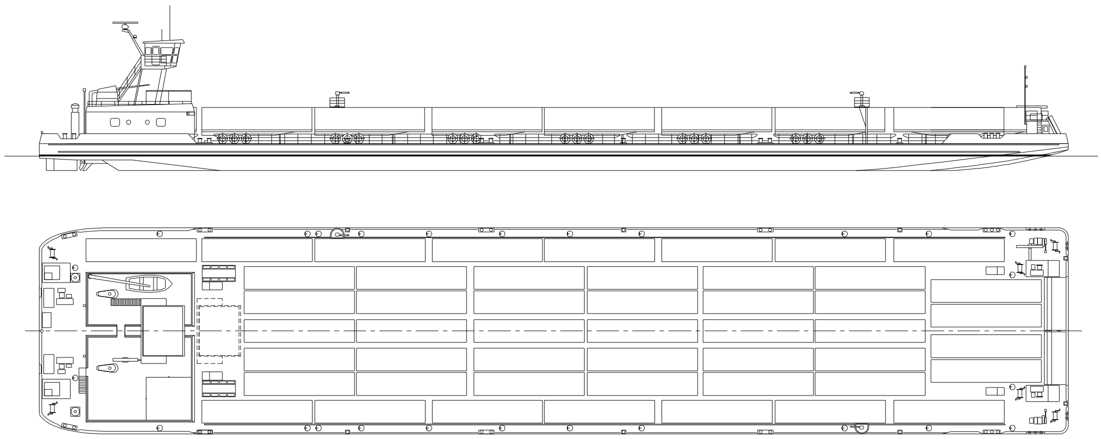


Fig. 2.10 Danube semi-catamaran (built in Deggendorf)

The main particulars of these four vessels are as follows:

Length overall	114.0 m
Breadth maximal	22.8 m
Depth	3.0 m (ships built in Serbia 3.3 m)
Draught fully loaded	1.65 m
Deadweight	1530 tons
Cargo capacity	1372 tons (49 road trailers, 28 tons each)
Engine output	2 x 910 kW
Service speed	18 km/h (in streamless water)
Crew accommodation for	12 persons (16 on ships built in Serbia)

The ships were equipped with bow thruster, elevating wheelhouse, at that time the most modern nautical devices (two radars, rate of turn indicators, radio-communication facilities, echo-sounders, TV camera on bows and monitor in the wheelhouse), two hydraulically powered folding bow ramps, fire-fighting monitors, ballasting system, a certain number of electric sockets on cargo deck for refrigerating trailers etc. The vessels were built in accordance with the GL rules and ADNR norms.

This fleet provides in average 90 roundtrips per year on the route Passau-Vidin-Passau with optional stops in Linz and Vienna. Each roundtrip lasts two weeks, even though according to the ship performances, this time could be shortened to 11-12 days.

Fig. 2.11 Danube catamaran (built in Apatin, Serbia)

Following the successful effects of this first Ro-Ro service on the Danube, the German-Hungarian joint venture "Hungaro Lloyd" established the regular Ro-Ro line between Passau and Budapest in 1992. The "Hungaro Lloyd" fleet consists of four reconstructed and properly equipped pushed barges of Europe IIb type of the following characteristics:

Length overall	76.5 m
Breadth maximal	11.4 m
Draught fully loaded	2.7 m
Cargo capacity	1800 tons or 32 road semi-trailers

These barges designated as "RO RO 51" through "RO RO 54" have two trailer decks and are equipped with one 15 m long inner ramp to enable access either to upper or lower deck, one two-fold ramp astern for ship-to-shore transhipment, ballasting system and one diesel aggregate for power supply. The ramps are hydraulically operated. Two barges - "RO RO 53" and "RO RO 54" are additionally equipped with 220 kW bow thrusters. The convoys of two barges, whereby one with bow thruster, are pushed by one 2200 kW push-boat, usually chartered Bulgarian "Naidan Kirov" class vessels.

The convoy capacity is 64 forty-feet semi-trailers. The scheduled departures from Passau were each Monday afternoon, and from Budapest each Thursday morning.

Danube catamarans and Ro-Ro barges are also sporadically used for transports of new passenger cars from German ports on the upper Danube to Vienna or Budapest. Thereby, the capacity of one leg is between 200 and 250 cars.

The Austrian DDSG has also reconstructed two SL 18000 type barges of its fleet and equipped them for Roll-on-Roll-off transhipment and transports of single piece cargoes of extraordinary weight and dimensions. Besides, the Slovak SPD has 4 Ro-Ro barges of Europe II type, Ukrainian UDP several flat deck barges of "PDM-10" type and foldable ramp on bows and Serbian BBP two self-propelled river vessel and four barges reconstructed for passenger car transports on its three decks. According to the last information, the Romanian shipyard in Orsova reconstructed two Europe II barges and equipped them as four-deck passenger cars carriers. One vessel is delivered to the customer in Cologne while the second will be put into service on the Upper Danube.

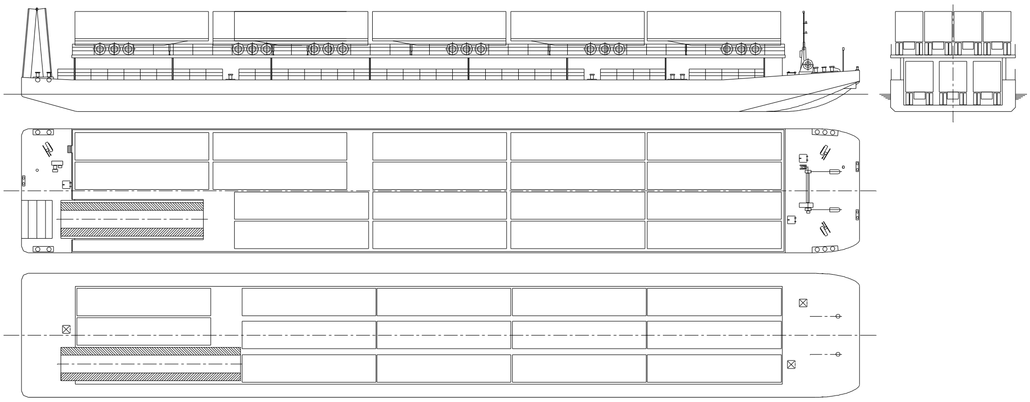


Fig. 2.12 Ro-Ro barge of "Hungaro Lloyd"

For about twenty years or so Ro-Ro terminals exist in Regensburg, Passau, Linz, Vienna, Bratislava, Budapest, Vidin, Rousse and Izmail. Recognizing the benefits of Ro-Ro transport two additional Ro-Ro terminals were built in Hungary in ports of Gyor-Gonyu and Baja, while in Bulgaria it is planned to open a terminal in the port of Lom. Concerning Serbia, the construction of a Ro-Ro terminal is planned in ports of Belgrade and of Pancevo (the Danube port near Belgrade).

Finally, it is worth mentioning the idea born in Belgrade by the group of experts at the end of eighties/beginning of nineties to reconstruct and rebuilt a number of existing domestic Danube ships. These relatively new and well equipped vessels were not utilised economically for the purpose they were originally built for (transport of gravel, i.e. specifically heavy cargo). However, according to all preliminary analyses, vessels would be well used for the transport of specifically lightweight semi-trailers for the Passau-Belgrade service (1067 km). The vessels suppose to have the following principal particulars (after reconstruction into Ro-Ro carriers):

Length over all	94.70 m
Breadth max.	11.05 m
Depth	2.80 m
Draught max.	1.60 m
Air draft	6.50 m
Main engines output	2 x 350 kW
Speed (water depth 5m)	16 km/h
Crew	8 persons
Payload	730 t
Capacity	18 trailers.

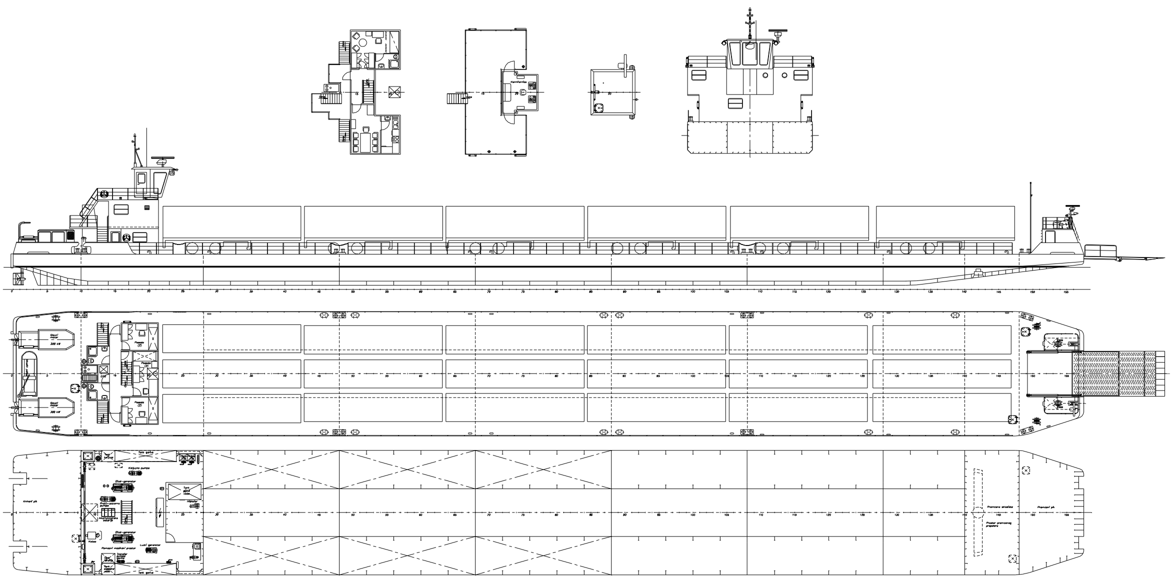


Fig. 2.13 Ro-Ro vessel for Passau-Belgrade service

Alternatively, in order to achieve speeds through the water of up to about 20 km/h, the propulsion engines could be replaced by more powerful units of 2 x 650 kW. This very simplified, but hence also relatively cheap vessel could carry on 18 forty-foot semi-trailers. The version for accompanied transport - drawing vehicles with drivers on board, with proper accommodation for drivers as passengers, rearranged superstructure and reduced capacity (12 trucks with semi-trailers, see Fig. 2.14) - was also seriously considered.

It was assumed that the fleet of these vessels could be quickly and cheaply obtained through the proposed reconstruction of existing ships. Some 7 of 8 units were considered at the beginning as duly enough to maintain daily service between Passau and Belgrade and eventually, after gaining experience and stable market share, to be gradually appended by new purposely built Ro-Ro ships with optimally tuned characteristics (size, speed, equipment etc.). But the events in former Yugoslavia at the beginning of nineties interrupted this promising initiative.

2.2.3 Technical Aspects of the Danube Ro-Ro Services
(from MUTAND Prefeasibility Study)

a) Types of services

When considering the road and inland waterway mode (the same is for road and railway) two types of intermodal services exist: accompanied and unaccompanied. In case of the so-called unaccompanied service only the freight unit is transferred from vehicle to vehicle (trailer, semi-trailer, swap body, container) while the truck (road drawing vehicle) and driver are not on board during the waterborne segment of the transport chain. Accompanied transport includes the presence of truck on board and in most cases also the driver. Both options have certain advantages and disadvantages too.

To which of them preference will be given, depends on factors like transport distance, traffic rules and regulations on the local road network, the level of organisation and mutual co-operation among transport actors etc. From a pure technical point of view, unaccompanied transports are more reasonable, at least because the stowage rate and payload capacity is higher.

The Ro-Ro ship has a certain number of lane-meters for stowing the vehicles, and trucks (drawing units) occupy them instead of leaving them free to be used by trailers/semi-trailers. The illustrative example is given in Fig. 2.13 and 2,14. The version of the same ship dedicated exclusively to an unaccompanied transport has a capacity of 18 semi-trailers, while the vessel for accompanied combined transport has a considerably reduced effective capacity of only 12 semi-trailers, not only due to deck space occupied by the trucks (drawing vehicles with semi-trailers), but also due to larger deckhouse to accommodate 12 truck drivers. Namely, truck drivers on board the ship must be treated as passengers and that increases regulation demands for premises and facilities on board. Moreover, in case that more than 12 drivers are envisaged to be on board, the ship must be classified as “passenger vessel” and more demanding general and safety rules must be applied.

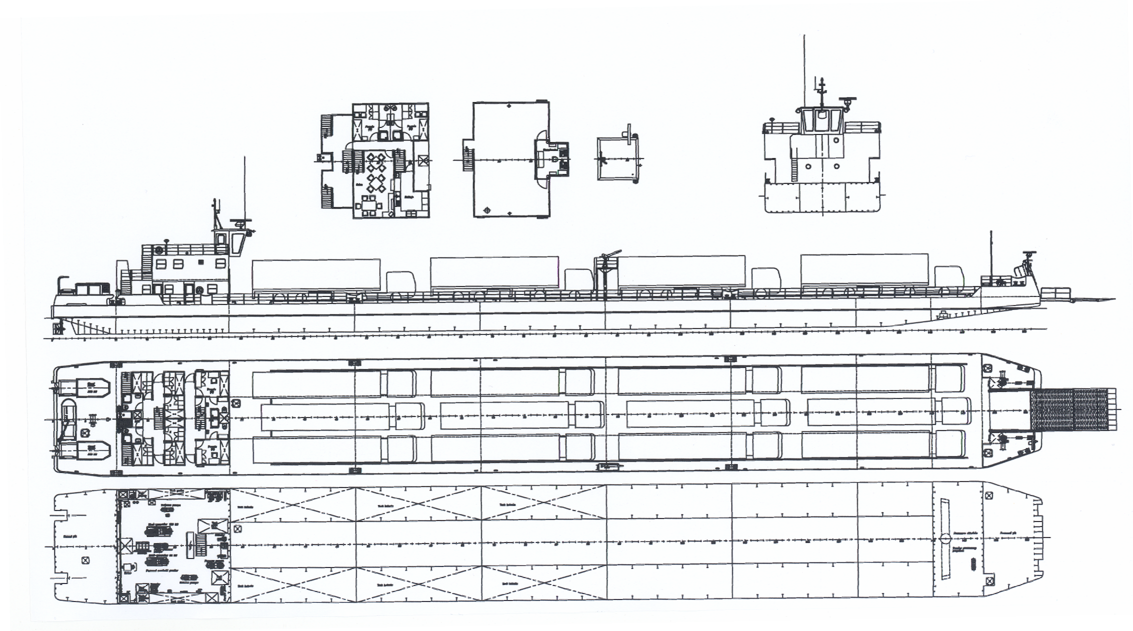


Fig. 2.14 Ro-Ro vessel for Passau-Belgrade service (accompanied transport)

b) Types of operation

Two types of operation might be distinguished:

- “point-to-point” meaning the waterborne segment only between end-terminals on the route, without any intermediate stops to reload the cargo.

- “bus-stop” with one or more regular or optional intermediate stops in order to reload the freight units (horizontally i.e. “Roll-on/roll-off” or vertically i.e. “Load-on/load-of" in case of containers, or optionally swap bodies - makes no difference) in terminals located between the end stations.

The right choice of the kind of operation must be preceded by a comprehensive logistic analysis because it influences design of the ship and ship-to-shore transshipment facilities in terminals. Point-to-point operation enables a longitudinal stowage of trailers/semi-trailers on deck and provides a higher stowage utilisation rate (denser stowage) – nevertheless, enough to bring clear economic effects! This, however, excludes random access of vehicles on board (transversal stowage, Fig. 2.15) desperately needed for bus-stop mode of operation. Namely, it is obvious that longitudinal stowage would require a better organisation and processing of the embarking scheme (who comes first, who comes later, schedule of embarkment) in case the ship operates in bus-stop mode.

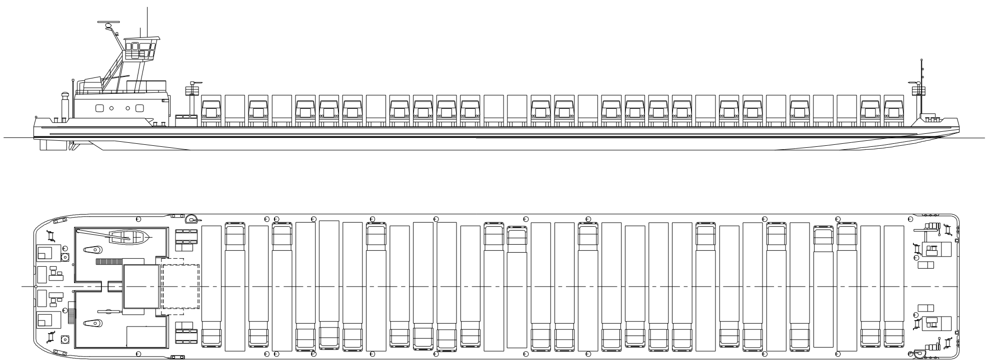


Fig. 2.15 River Ro-Ro vessel with random access on board

2.2.4 Future Danube Ro-Ro ships of II generation

Discussion concerning the size of the Danube Ro-Ro vessels does not differ much from that about he Danube container vessels (see Section 2.1.2), except regarding the draught (T). Namely, as shown, the Danube container vessels can carry 2, 3 or 4 container layers, and therefore, have a draught of 1.60-1.85 m, 2.25-2.50 m or 3.00-3.25 m, respectively (see Fig. 2.5). So, due to shallow water, unloading of containers is feasible. Obviously, the Ro-Ro vessels cannot apply the same technique – unloading of trucks/trailers. In addition, very useful feedback information from the experienced and most successful Danube Ro-Ro service provider is that desirable loaded draught should not exceed 1.4 m. This value, although looks unfeasible at the first glance, has to be respected and seriously considered when Ro-Ro ships of the next generation are designed.

Furthermore, road vehicles (trucks, trailers) might be regarded as a relatively light cargo which requires large deck area. So, it is possible to obtain a well balanced ship (see Section 2.1.4) satisfying recommended low draught of 1.4 to 1.5 m only. Hence, semi-catamaran hull form, mentioned in SPIN-Rhine Section 1.2.1.2, is a desirable form for

Ro-Ro ships, but not container ships due to low available container mass (as explained in Section 2.1.4).

Consequently, four different ships in the MUTAND Prefeasibility Study were assumed and analysed:

- Ship A having capacity of 60 semi-trailers
- Ship B with 50 semi-trailers
- Ship C with 35 semi-trailers
- Ship D with 18 semi-trailers

In the first approximation the maximal feasible size of the vessel of 135 x 23 m (ship would be similar in appearance to the existing catamarans shown in Figures 2.10 and 2.11), with additional capacity of up to 60 semi-trailers may be assumed. These new ships should remain single deck vessels due to restricted draught as well as the clearance of some critical bridges upstream of Budapest. However, smaller units might, and should be, also considered. Slender ships with higher L/B ratio would reduce the power requirements at the same speed. For longitudinal stowage the breadth could be reduced in steps of 2.8 m (width of the lane) to 20.2 m, 17.4 m etc. The 135 m long Ro-Ro vessel with the beam of 20.2 m could probably accommodate up to 52 semi-trailers and that with 17.4 m up to 44.

In the case of transversal stowage of vehicles on deck (in order to enable random access and hence an efficient “bus-stop” service) the breadth margin should be set at about 18.5 m. The reason is that the huge majority of trucks on long haulage trips draw semi-trailers with total vehicle length of to 16.5 m. It might be expected that the share of 16.5 m trucks will increase in the future (due to semi-trailers of 40- or 45-feet i.e. about 12.2 and 13.7 m respectively). A ship of 135 x 18.5 m and with transverse stowage pattern would be able to accommodate only 35 to 36 vehicles (transversal lanes on deck). Thereby, the advantage of better capacity utilisation at longitudinal stowage is more than evident. However, narrower ship with lower total weight would permit more freedom during the design process, i.e. would allow hull optimisation from hydrodynamic and structural point of view, which will also result in somewhat reduced building costs.

In the MUTAND Prefeasibility Study the Passau-Belgrade-Passau service has been analysed assuming the speed of 16 km/h through the water of 5 m depth. The route was segmented into voyage scenario with adequate speed and time parameters previously analysed. Principal particulars of hypothetical vessels A to D are given in Table 4.

Table 4 Principal particulars of assumed vessels

SHIP		**A**	**B**	**C**	**D**
Length	(m)	135	115	115	95
Breadth	(m)	23	23	18	11
Installed power	(kW)	1600	1400	1200	700
Crew	(persons)	12	12	12	8
Vehicles	(semi-trailers/trucks)	60/42	50/35	35/25	18/12

Some of the MUTAND's conclusions and recommendations follow:

- Transfer of services and technical solutions from the Rhine with its better developed traffic condition is not possible and new technical, organisational and other solutions should be developed particularly for the Danube.

- Over short and probably medium terms, the preference is given to the implementation of Ro-Ro rather than to container transport on account of a lower initial capital investment.

- Preliminary cost analyses for the point-to-point Belgrade-Passau-Belgrade Ro-Ro service were done based on four different ship sizes. The reasonable variations on ship building costs (ranging from "low" to "high") and the number of vehicles on board ("high" for unaccompanied and "low" for accompanied transports) were taken into account. Under assumptions which are explained in the main part of the MUTAND Study, the benefits in monetary terms are shown in Fig. 2.16. As expected, larger vessels A and B are more efficient than smaller ones. It should be underlined, however, that several other benefits which cannot be quantified in monetary terms (insufficient number of truck quotas, environmental cleanness, safety etc.) might be achieved with the Ro-Ro transport.

	L x B	Capacity
•	A – 135 x 23 m	60/42
•	B – 115 x 23 m	50/35
•	C – 115 x 18 m	35/25
•	D – 95 x 11 m	18/12

Belgrade-Passau-Belgrade

- **by road – 6 days**
- **by ship – 7 days**

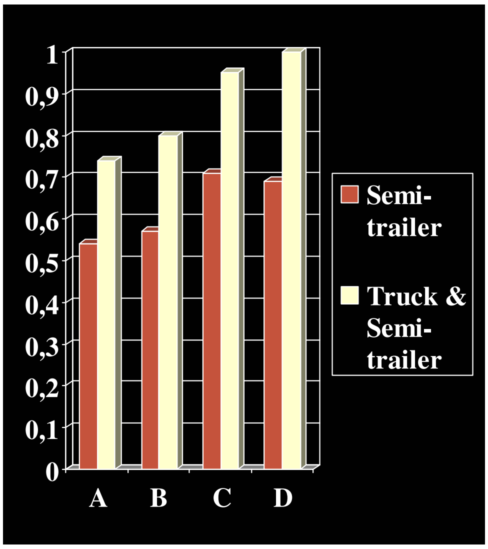


Fig. 2.16 Ratio of Ro-Ro to road prices

The comparison of transport costs and transport time by road and combined transport using the Ro-Ro ship on the main leg shows that:

- The costs and therefore the price of Ro-Ro service might be very attractive for truckers moving between Belgrade and Southern Germany (as shown above, when carrying semi-trailers Ro-Ro price may be up to twice lower than truck's road price).

- Ship travel time is only one day longer than necessary road time (about 7 instead of about 6 days) on the Belgrade- Passau-Belgrade route.

- Considerable cost savings are in favour of semi-trailers compared to trucks.

- There are some indications that smaller but simpler, and thus much cheaper vessels, might be an interesting alternative to the more economical larger vessels.

2.3 Barge Trains

Barge trains of different sizes are widely used on the Danube (standard breath of barges used to be 11 m, now is 11.4 m, in addition to that many of them are of 9.5 m etc., not to mention old towing vessels sometimes used in pushed trains). However, in the context of this Working Paper, only container barges, i.e. those of 11.4 m (four container layer abreast) should be mentioned (Ro-Ro barges are mentioned in Section 2.2.2). These are actually standard Europe II barges with a draught of 2.5 m (see Table 2 and Figures 9 and 10 in SPIN-Rhine). By the way, according to SPIN-Rhine, these are Europe IIc barges, while in the Danube corridor countries they are called Europe IIb barges.

Danube-sea barges could also be found on the Danube waterway. They were transported by large ocean-going barge-carriers of Yulius Futcik class built in Finland (Interlighter concept, their Western counterpart were Seebee ships). Danube-sea barges are 38.25 m long, so that two coupled barges correspond to one standard Danube (river) barge of 76.5 m (other particularies are B=11 m, H=3.9 m, T=3.3 m, corresponding dwt=1070 t, lightship weight 240 t).

A push train (push-boat + barges) or a coupling train (motor ship + barge), even of partly loaded barges, can be a good answer to restricted draught problem, taking into account that power needed to push an additional barge (or few of them) rises slightly, while container capacity can increase rapidly (compared to that of self-propelled vessel). Possible arrangements of pushing and coupling trains, according to ECE classification, are shown in SPIN-Rhine Fig. 12, which is obviously applicable to the Danube waterway too (in this context, Tables 2 and 3 should also be consulted).

3. NEW TECHNOLOGIES APPLICABLE ON THE DANUBE VESSELS

When talking about more efficient ship of the future, special attention should be paid to the following:

- Reduction of fuel consumption (hence, pollution reduction too)
- Intermodality (hence reduction of indirect costs)
- Increase of safety measures
- Crew reduction.

Although all four mentioned groups are important, only the first one will be discussed in more details. In that context see Fig. 3.1 which originates from (Spyrou 1988), but is changed and adapted to present needs. Discussion according to subjects presented in Fig. 3.1 follows:

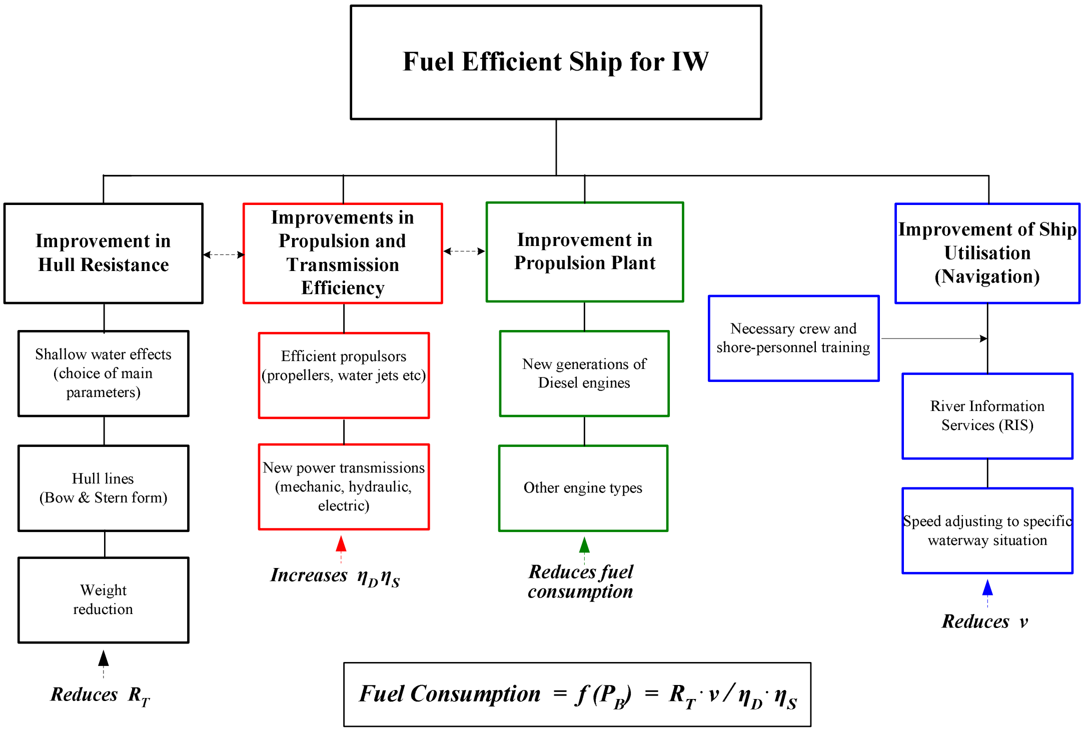


Fig 3.1 Fuel efficient ship for inland waterway

3.1 Improvements in Hull Resistance

3.1.1 Ship form

As already stated in Section 1.2, shallow water effects are of primary importance for choosing the main ship parameters – vessel's speed and length should be adapted to waterway (water depth), see Figures 1.1. to 1.3. The secondary hull form parameters, mainly the bow and stern form, also influence resistance. Contemporary inland vessels have lower resistance (in some cases up to 50%) than those of few decades ago (Zoelner

2003). It should be stated, however, that good low-resistance hull form can be obtained only if advices of the experts are followed, and often after model experiments are carried out in specialized towing tanks (in this respect, leading European institutes are VBD, Duisburg and MARIN, Wageningen).

In this context, the results of VEBIS Project (Zibell and Mueller 1996) are very useful. VEBIS Project treated optimal units for variable transport tasks and regimes of operation. Hints and recommendations for design of inland ships for extremely shallow water, without delay, can be applied to the vessels of ECE class IV and V intended for the Danube and its tributaries, Fig. 3.2.

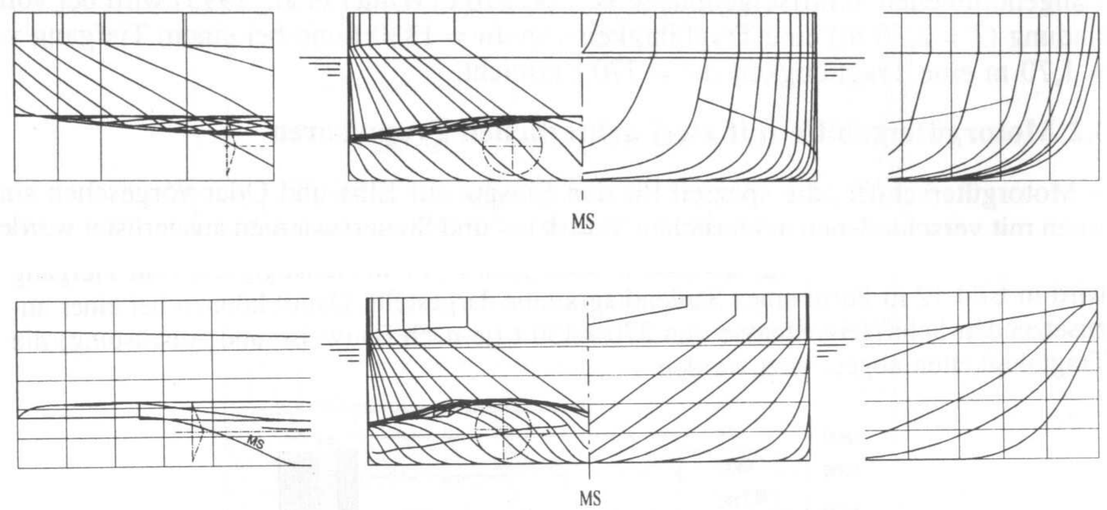


Fig. 3.2 Twin screw ship (Type I and from it developed Type IV) L=82 m, B=9.5 m, T=2.5 m, TEU 77, propellers in nozzles with conventional rudders)

3.1.2 Ship weight

Low-speed inland vessels (treated in Section 2) are made exclusively of steel and are very durable since their life is usually 50 years, often more. As a matter of fact, hull construction of contemporary transport vessels do not differ much from those of few decades ago, hence their weight also didn't change much. Possibilities to introduce the new materials targeted to hull weight reduction, as are for instance aluminum or GRP (glass reinforced plastic), are low. However, the superstructure, for instance, could be built of aluminum, but reduction of overall weight would be relatively negligible. High tensile steels could be used for hull construction and probably the sandwich panels of prefabricated steel plates.

Use of steel panels, called "I-core^{R}" (developed by Mayer Werft), is still in the experimental phase. Some recent projects, for instance (Jastrzebski 1993), reported structural weight savings of around 40% if steel sandwich panels would be used for a small barge of 32.5 m, see Fig. 3.3. It is stated that use of I-core^{R} panels simplifies barge production as well as maintenance. In essence, the Sandwich Plate System (SPS) replaces a traditional steel plate with stiffeners welded to its underside, by a simple arrangement of two plates with welded perimeter bars and with an elastomer injected between to form a solid unit (see Ship & Boat Int. 9/10-2003).

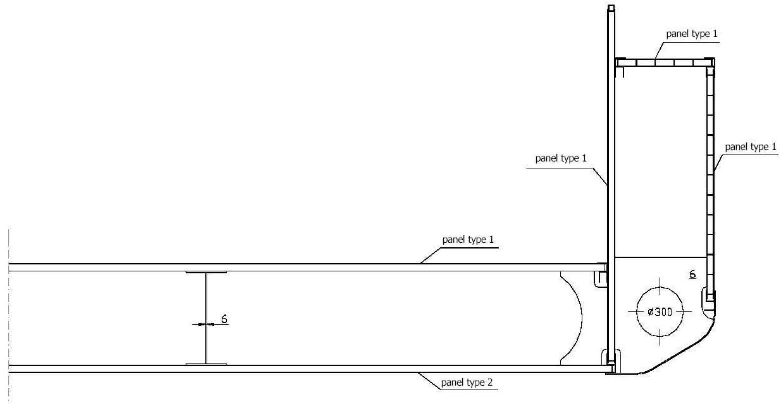


Fig. 3.3 Typical frame cross section of I-coreR panel barge

Conventional approach to ship hull construction means that the Classification Societies' Rules for dimensioning the hull structure members should be applied. Nevertheless, implementation of Rule's recommendations and formulas for dimensioning structure are not purely a technical matter. For instance, comparing the weight of standard Europe IIb barges made in accordance to Russian and German rules (GL), an unexpected result was obtained, i.e. barges made according to the GL rules were heavier than those made in accordance to Russian rules. Explanation for this is that German work-force is more expensive (what was incorporated into GL) resulting in fewer but thicker hull elements. Russian rules were following opposite needs (cheaper work-force but costly material), so their barges were lighter but more expensive to build.

Similarly, GL rules which are often used for the dimensioning of large self-propelled inland vessels (as treated in Section 2), pose a restriction that the ratio L/H should be less than 35 (if not, the direct calculation are necessary). This, actually, stems from the Rhine vessels which, having larger draught (than the Danube vessels), also have larger side height (H). L/H ratio for large Danube vessels might be larger than 40.

Consequently, it would be appropriate to adapt the Classification Societies' Rules to the Danube needs, otherwise more complicated direct calculations (numeric or analytic) have to be applied.

3.2 Innovations in Propulsion and Transmissions

3.2.1 Screw propellers

The main propulsors which are used (or may be used) on inland vessels are based on a screw-propeller (or just propeller); these are the following:

- Monoblock or **Fixed-pitch - FPP** naked propeller (simple and cheap, nowadays have up to 7 skewed blades for reduced vibrations).
- **Controllable pitch propeller - CPP** (can adapt to resistance variations due to change of water depth, advantageous for faster vessels)
- **Propeller in nozzle** (increases thrust if propeller diameter is restricted – usual case)
- **Tandem propellers** (two propellers turning in same direction; efficiency is between FPP and CRP)
- **Contra rotating propellers - CRP** (two propellers turning in opposite direction, have the highest efficiency among all propulsors)
- **Surface piercing propellers - SPP** (for extremely high speeds, feasible for shallow water since only half of the propeller disc is immersed).

Of course, possible are combinations of above, for instance CPP in a nozzle etc. Since the Danube is a shallow river, propeller diameter will almost always be restricted and therefore, a nozzle is necessary for majority of vessel types. According to the VEBIS study, wake-adapted nozzle should be used, see Fig. 3.4. A bit faster vessels will need shorter nozzle and very fast ones (for transcritical speeds) should be naked. Probably slotted nozzles, although more complicated, should also be considered to be applied on inland vessels.

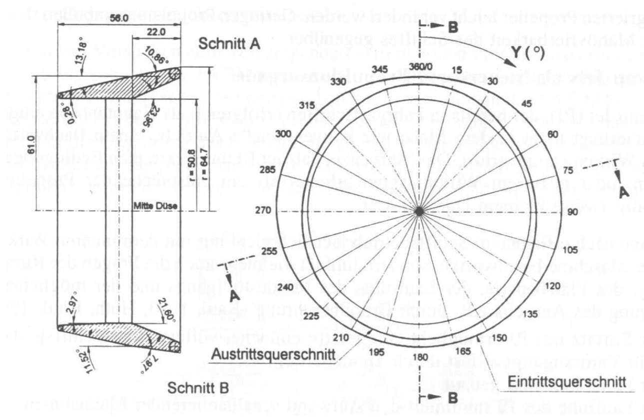


Fig. 3.4 Unconventional wake-adapted nozzle

With traditional shafting arrangement, rudders are necessary. They have to be treated together with propulsors. An interesting combination of rudders and a nozzle is depicted in Fig 3.5, showing Canadian Integrated Nautican nozzle with triple rudders, which enable simple installation and provide good characteristics (high aspect ratio triple rudders).

Fig. 3.5 Integrated Nautican nozzle with triple rudders

Transmission of power from the engine (usually Diesel) can be:
- **Mechanical – horizontal** (traditional and usual case, rudder is necessary)
- **Mechanical – vertical** (rudder-propeller or azimuthing thruster, turn 360 deg.)
- **Electrical** (Diesel-electric propulsion – (electric) pod propulsor)
- **Hydraulic** (Diesel – hydraulic propulsion – hydrostatic pod propulsor).

Usual transmission losses are around 4% (with gearbox), 10%, 10-15% and 15-20%, respectively. Obviously, transmission losses in some cases are very high, which is often forgotten (note that last 50 years of propeller development increased its efficiency probably for some 5% only!).

Nevertheless, it is not only the efficiency which counts. The need for **enhanced maneuverability** is often more important (capabilities which rudder propeller possesses, for instance), or extra space obtained due to the feasibility to install the generating plant in convenient (less needed) spaces in ship's hull – see INBISHIP concept (Werft 1999), etc.

Consequently, promising propeller-based propulsors for inland waterways would be the following:

- Propellers in nozzles (FPP and CPP but with new – improved - seal types), with vertical or horizontal (mechanical) power transmission – Fig. 3.6
- Tandem and CRP with mechanical transmission – Fig. 3.7 and 3.8 respectively
- Pod propulsors (INBISHIP concept) with FPP – Fig. 3.9
- Combinations of horizontal mechanical and pod propulsors – Fig. 4.7, for instance.

Figure 3.6 Rudder-propeller in an integrated nozzle

VETH (FPP) & Aquamaster RR (CPP)

Figure 3.7 Tandem propeller
Shottel Twin Propeller - STP

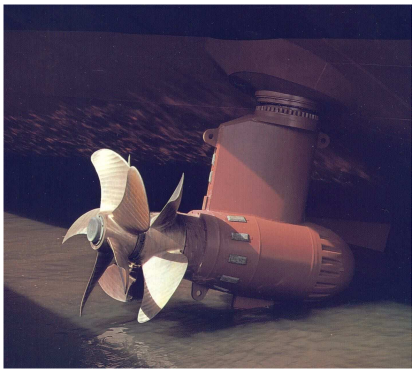


Figure 3.8 CRP Ulstein Aquamaster RR

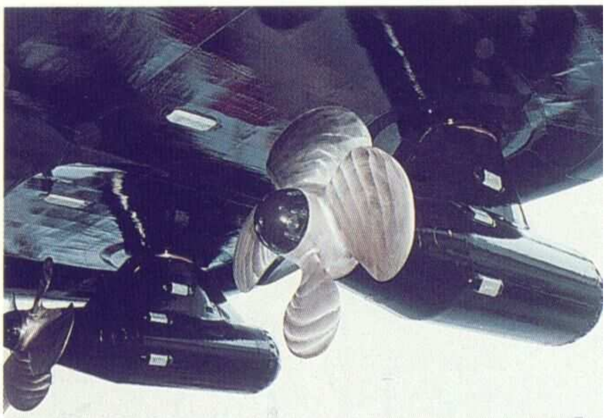


Figure 3.9 Pod propulsors (the Azipod drives of a river icebreaker Roethelstein)

Concerning pod propulsors, probably the first units of Azipod type used on inland waterways was on Austrian river icebreaker Roethelstein (see Figures 3.9 and 4.8). Azipod is a trade name of a first pod propulsor on the market (produced by Finish Kvaerner Masa + ABB). Azipod propulsor was followed with products named Mermaid (KaMeWa RR + Cegelec), Dolphin (ex LIPS + Atlas) and SSP (Schottel + Siemens) and generally can work in push or pull mode. Well known INBISHIP Project was based on Azipods since it seams they are still the only producers of compact pod propulsors.

Since inland vessels usually use shrouded propellers in nozzles which are countersunk in the tunnel, it is possible to transmit power to the propeller via a geared ring attached to the blade tips situated inside the nozzle (hence the gear-box is also incorporated). That would be a tip-driven propeller without classical shafts, see (Radojcic 1997), which would have, amongst other, good un-obstacled water inflow. A kind of an electrical tip-driven propeller (with both, stator and rotor integrated in the nozzle) has been developed by Westinghouse (called Integral Electric Motor Propeller – IM/P) and AEG-JASTRAM (Elektrischer Motorpropeller), and recently by General Dynamics Electric Boat (Rim-Driven Propeller - RDP). These new devices seem quite promising for application on the river vessels, Fig. 3.10.

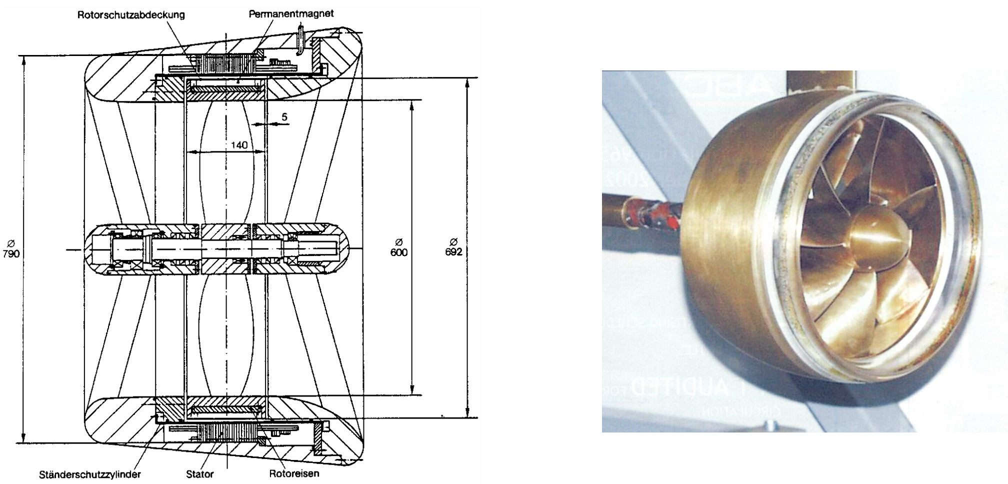


Fig. 3.10 Tip-driven (rim-driven) electric motor propeller
(AEG-Jastram and GD prototypes)

3.2.2 Other propulsors

Not counting the clumsy paddle wheels, which by the way have good efficiency and are inherently adapted to shallow draught (river) vessels, promising propulsors could be:

- Vertical propeller (produced only by Voith and therefore often called Voith-Schneider propeller)
- Waterjet.

Both propulsors have a vertical axis (see Fig. 3.11 and 3,12), which principally permits enlargement of a diameter, while their height (restricted by draught) need not to be changed. Thus, their efficiency/usefulness in the shallow water could be increased.

Vertical propeller (Fig. 3.11) might be used on the vessels requiring very good maneouverability, since they can produce controllable thrust throughout 360 deg. (their conventional counterpart would be a rudder-CPP). Nevertheless, vertical propellers are relatively complicated and therefore expensive.

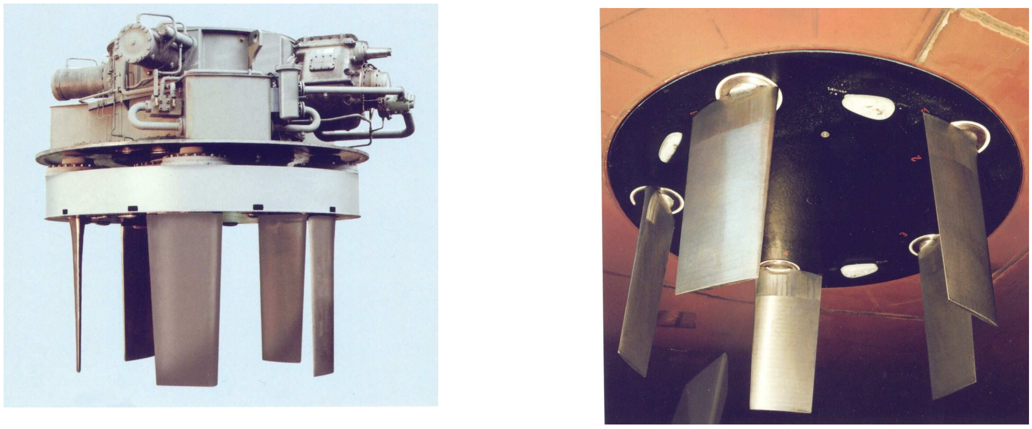


Figure 3.11 Vertical Voith-Schneider propeller

There are several types of waterjets, but those which are used on river vessels are usually made by Schottel and are called Pump-jets (initially developed to be a bow-thruster) – Fig. 3.12. They consist of a mixed-flow pump placed in a special volute casing which can rotate about its vertical axis, enabling steering throughout 360 deg. Water is drawn into the casing below the hull and is expelled through the outlet nozzle. Advantages are applicability to a very shallow draught vessels, good maneuverability, simple hull forms (see Fig. 3.13 from VEBIS project), robustness (even grounding is allowed), reduced jamming etc. Disadvantage could be a relatively high cost.

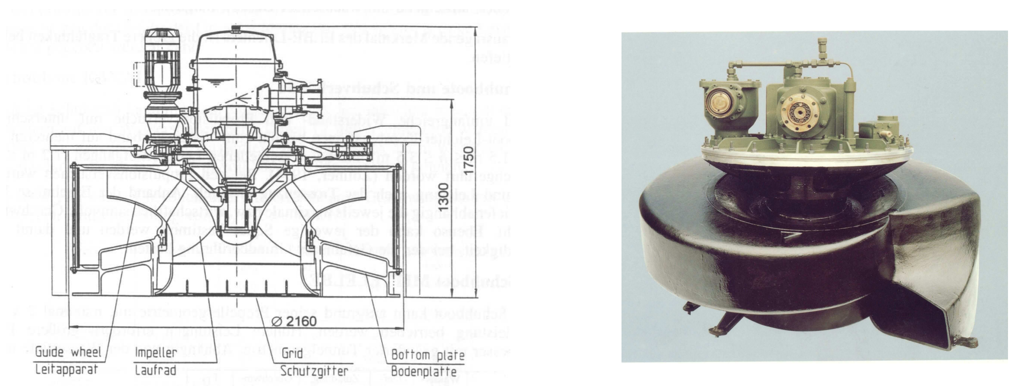


Fig. 3.12 Schottel Pump Jet

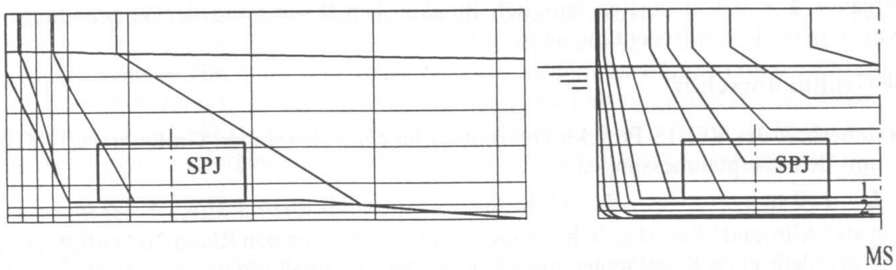


Figure 3.13 Aftship of a Type II hull form for Schottel Pump Jet
(corresponds to hulls shown in Fig 3.2)

Besides these propulsors, promising might be different kinds of "fish and whale tail propulsors", but these are still in the experimental phase (for instance in MARIN).

3.3 Propulsion Plants (Engines)

3.3.1 New generations of Diesel Engines

Shipbuilding and shipping industry, particularly on inland waterways, is a relatively small sector to be a leader in the development of new types of propulsion-plants. Engines that are nowadays used on inland ships are marinized general-application Diesel engines. They often have 1500 or 1800 rpm (generating-set engines for 50 or 60 Hz, respectively) and are, therefore, lighter and cheaper than their predecessors having around 700-800 rpm. As a consequence, contemporary gearboxes have higher gear ratios than those of few decades ago. It is expected that this trend will continue in the future.

Diesel engines (and fuels) are constantly developed with the aim, among other, to reduce harmful emissions. The quantity of following substances in exhaust gasses are usually regarded as relevant for evaluating Diesel engine cleanness:
- Nitrogen oxide, NO and NO_2 (NO_X)
- Sulphur oxides. SO and SO_2 (SO_X)
- Unicirated hydrocarbon compounds (HC_X)

- Carbon dioxide (CO_2)
- Carbon monoxide (CO)
- Soot particles (PM).

Among these, probably the most relevant single substance is carbon dioxide (CO_2) which cause climate change (global warming). CO_2 emissions are almost directly proportional to fuel consumption. On the other side, optimised quantity of NO_X in the exhaust gasses (impacts eutrophication and acidification) does not correspond to optimal fuel consumption. The other substances also have effect on environment, so sooner or later different kind of legislation measures will gradually have to be implemented everywhere - on inland waterways too.

For instance, on the Rhine (since January 2002) NO_X emissions for all engines within the range of 500-2800 rpm have to be in accordance with Rheinsh regulations (adapted IMO regulations). Furthermore, permissible quantity of NO_X emissions changes every five years, so it might be expected that high speed Diesel engines will soon have to be equipped with expensive catalytic reactors. Sooner or later legislation measures implemented on the Rhine will evolve to European inland waterway measures.

3.3.2 Other engines

Aside from the Diesel engine which dominates the inland waterways nowadays, a promising engine could be (aero-derived or industrial) gas turbine which has several advantages (exceptionally high power to weight ratio, reliability, controllable exhaust gasses, etc.), but also some disadvantages (relatively efficient for very high powers (presently, above 5000 kW), still high fuel consumption, high cost).

Among promising engines are also various types of Fuel Cells (FC) (see Ship & Boat Int., for instance), which are still in the experimental phase. Presently worldwide R&D work is focused on road vehicles and stationary power plants with much less money been spent on marine propulsion, but the goal of zero emission is driving development of hydrogen FC and hydrogen storage methods. Not counting the experimental vessels equipped with FC, a kind of FC power is already used on submarines.

As a part of INBAT project, the FC power was also examined (see Zenczak et al. 2003). FC powered low-draught push-boat was compared to variants of Diesel power plant (with mechanical transmission, electric transmission and hydrostatic transmission). Regarding weight, FC power is comparable to conventional power plant with mechanical transmission, however, cost of around 100 $/kW is presently a great disadvantage.

More efficient and cleaner engines are obviously needed. However, according to some EST studies (Environmentally Sustainable Transport) major breakthroughs in this sector are not expected before 2025. In the meantime, abovementioned emission problems with Diesel engines will become even more pronounced. There is no doubt, however, that the environmental considerations will guide and force future engine development.

3.4 Innovations important for better ship utilisation (navigation) - RIS

River Information Services (RIS) provide possibilities for voyage planning, tracking and tracing, both from vessel and from shore side. Improved communication and information exchange within the system, indirectly contributes to the optimisation of the fuel consumption. This can be achieved, for instance, through the exchange of information related to lock operation, port/terminal planning, customs etc. on one side, and skipper on another, giving relevant information about the ship (her position, speed, destination, cargo etc.). According to received information, skipper can calculate estimated time of arrival (ETA) to certain destination, and, if possible, reduce/adjust ship's speed. Amongst other, this might result in significant reduction of fuel consumption.

Software solutions for advanced route planning are available nowadays. In some cases route-planning software relies on the data provided within the unique RIS environment. Planning procedures before the journey are also possible, since RIS provides reliable information about the water depth and potential obstacles on intended route. Inland ECDIS charts are in the first place developed to provide additional safety, but also enable navigation with an optimised speed.

After the initial success of German ELWIS, Austrian DORIS and EU project ALSO Danube, the importance of RIS for inland navigation rapidly increased. As a result, the COMPRIS Project, together with its extensions CRORIS and YURIS aim to be a further step towards the full implementation of the RIS on the Danube River. Moreover, EC prepares, the so-called RIS directive, which will set-up a legal framework for River Information Services in Europe.

4. SOME NOTICEABLE VESSELS ON THE DANUBE

In this section some noticeable (unusual) vessels of various types will be presented (container and Ro-Ro vessels have been presented in Section 2). The criteria for significance, having in mind the aim of this Working Paper, was chosen to be vessel's size or power installed, construction material, vessels type, installed equipment, number of sister ships built etc. It is believed that any of the abovementioned in some way might be important for the innovative Danube vessels. Obviously, the criteria are discussible, as well as the vessels chosen.

4.1 Pushboats and similar vessels

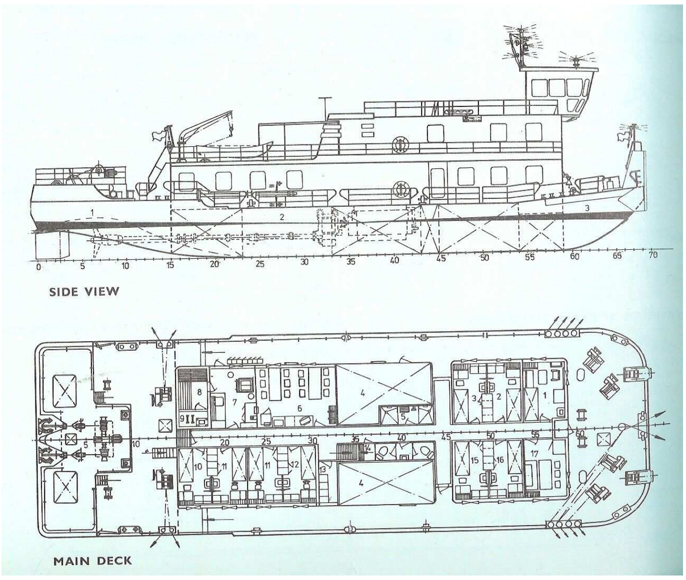
The pushboat technology was introduced on the Danube at the beginning of the sixties. First pushboats were "Kablar" and "Kosmaj" (owned by Yugoslav River Shipping Company – JRB). Soon after that, the pushboat technology was introduced in other Danube corridor countries and today pushboats dominate the Danube waterway. It should be noted that relatively large barge convoys were pushed, particularly on the Middle and Lower Danube, consisting often of 12 Danube II type barges; it was recorded that more than 35,000 t of cargo was pushed in one convoy.

Nevertheless, although somewhat obsolete, the towing technology was never quite abandoned, taking into account much smaller draught of towing tugs (compared to contemporary pushboats) which has some advantages particularly during the dry seasons when the water level is low.

Long range and harbor pushboats were built on the Danube and most of them had two propellers, but large pushboats with three propellers were not rare. Beside the draught restriction, the Danube pushboats generally differ from those on the Rhine in larger accommodation premises; namely, the Danube push boats have large crew working in shifts, aside the fact that the Danube is much longer river than the Rhine.

During the seventies, after some experience was gained, a kind of a standard or a recommendation emerged in Eastern Block shipping companies concerning the Danube long range pushboats. Besides the standardized mooring equipment, they suppose to have around 2 x 1200 HP (2 x 880 kW), length of around 35 m, breadth of 11 m (as the Danube barges) and draught of less than 1.9 m. These pushboats were built in series in all Danube countries downstream of Austria. So, for instance only in Oltenita in Rumania some thirty pushboats (sister ships) were built, see Fig. 4.1.

With almost the same particulars as above, four pushboats were built in Shipyard "Novi Sad" in mid eighties for SDP now UDP (Fig. 4.2) which are believed to be somewhat better than the other pushboats, probably due to the extensive model testing (in the cavitation tunnel too, which was rare); vessels were equipped for the first time with five bladed propellers in the nozzles which reduced ever present vibration and cavitation problems.



Loa = 34.6 m
B = 11.0 m
H = 2.8 m
T = 2. 0 m
P_B = 2 x 880 kW/750 rpm

Fig. 4.1 Standard pushboat of 2 x 1200 HP built in Oltenita, Rumania

Fig. 4.2 Pushboat “Brest”

Worth mentioning are probably still the largest pushboats on the Danube built in Shipyard “Tito” (now “Belgrade”) for JRB – “Karadjordje” and “Karlovac”, Fig. 4.3.

One of the pushboats was equipped with special system (device) for rudder unloading. The reason for this innovation was that large (floating) logs were often wedged in the nozzles or/and main/flanking rudders, which sometimes blocked or damaged the rudders (in particular case, there were 6 main and 4 flanking rudders). So, the purpose of the rudder unloading device was to permit the rest of the rudders (those which were not blocked by the log) to execute their function. Although the purpose of this invention sounds logical, soon after the launching the unloading device was replaced with the usual system of connecting rods (see general arrangement plan of “Karadjordje” - Fig. 4.4).

Loa = 40.45 m
B = 13.0 m
H = 2.8 m
T = 1.95 - 2.15 m
Main engines = 3 x 1294 kW
Speed with 12 barges of
1700 tdw each = 14 m/h

Fig. 4.3 The largest pushboats on the Danube “Karadjordje” and “Karlovac”

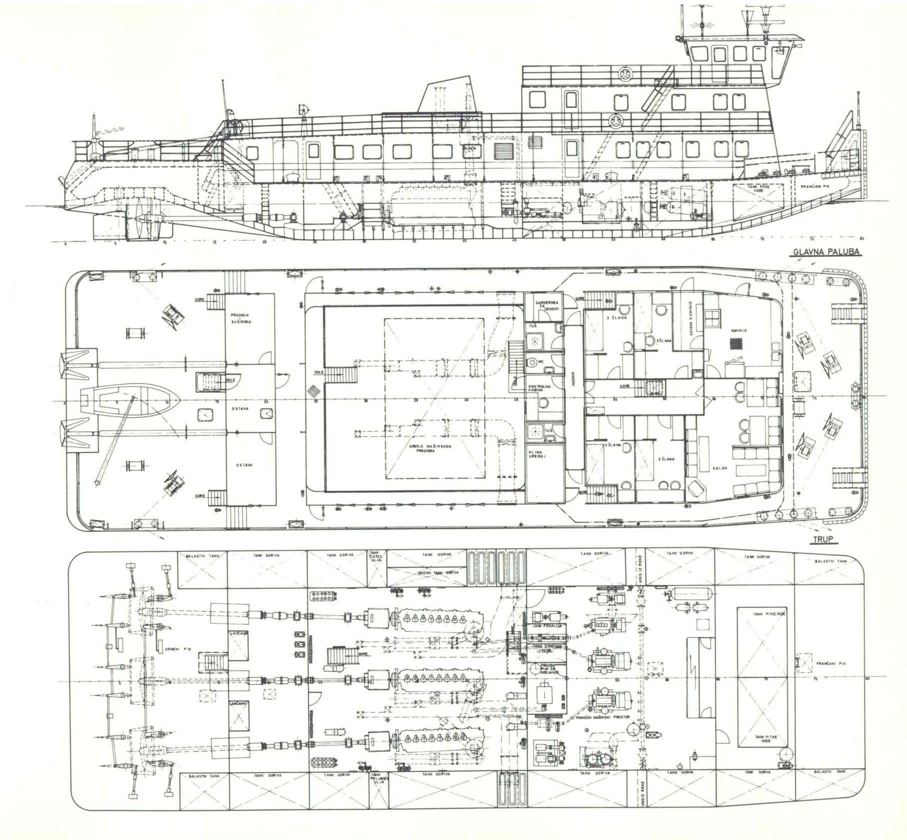


Fig. 4.4 General arrangement plan of “Karadjordje”

Some shipyards on the Danube could afford some experimenting and innovations. Among them was Shipyard “Tito”, now “Belgrade”, which built a special experimental vessel at the end of the eighties, called Modular Multi-Purpose Vessel – MMPO (Fig. 4.5).

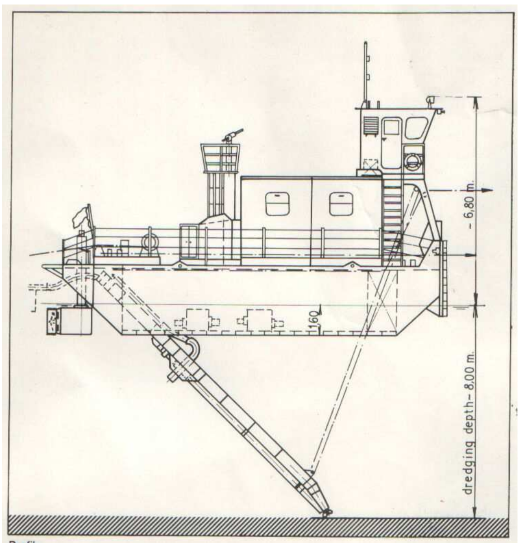
Fig. 4.5 Modular Multi-Purpose Vessel – MMPO

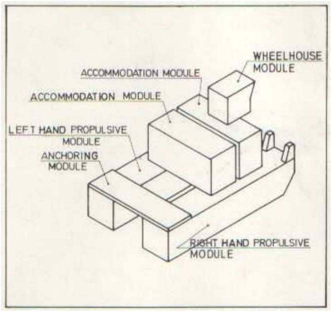
MMPO was designed by an Institute of Technical Sciences (of Serbian Academy of Sciences and Arts) and possessed several innovative features. Modular approach was accepted throughout; separate modules were interconnected by a special system of wedges (see Fig. 4.6). These are:

- Propulsive module with a driving complex
- Connecting modules – pallets – which provide stiffness (these were also the basis for two accommodation modules and an anchor-mooring winch module)
- Accommodation modules are standard containers including living and sanitary quarters
- Wheelhouse module.

Modularity enables easy manufacturing, quick assembling and dismantling providing easy transport of the vessel (its modules) by a truck, possibility to change layout/purpose of the vessel as well as her breath and draught etc. Furthermore, since the hydrostatic propulsion was used, various number of engines could be engaged according to the demand. In other words, the vessel could easily be transformed from a pushboat to a suction dredger or a vessel workshop etc. Besides the abovementioned, MMPO was equipped with two prototypes of hydrostatic rudder propulsors (pods). Anchor-mooring winch (with 6 drums), pumps etc. were also hydraulically driven, which eliminated the need for Diesel-electric generator sets (electrical installation with alternators was applied).

Loa = 13.75 m
$B_{propulsive\ module}$ = 2.4 m
B_{MAX} = 7.6 m
H = 2.4 m
T = 1.7 m
Fixed top point 8.5 m
Installed power 4 x 92 kW
No. of crew 2





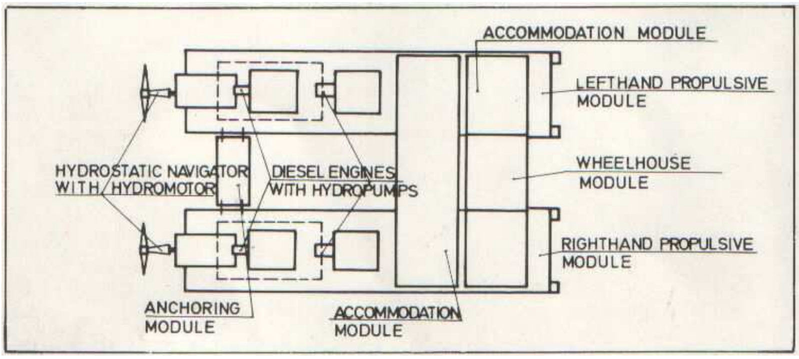
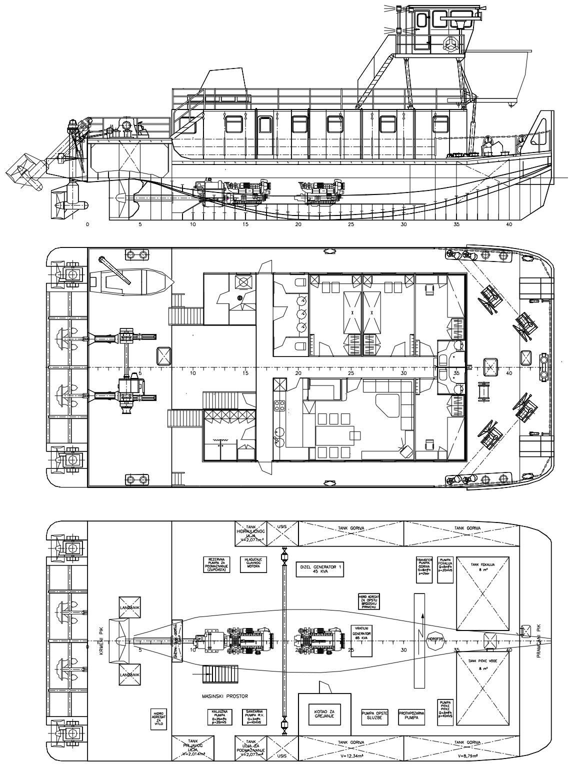


Fig. 4.6 MMPO's profile and modules

Findings and results obtained through exploitation of MMPO lead to the design of the so called "hybrid pushboat" (see Bilen and Zerjal 1998) whose general arrangement plan is shown on Fig. 4.7. Proposed hybrid pushboat suppose to have two Diesel engines (situated in line, one behind the other) driving three ducted propellers. A large central propeller (of 1.85 m) is mechanically driven via a gearbox and conventional propeller shaft, while the other Diesel engine drives two hydrostatic side propulsors (propellers of 1.35 m) via hydraulic transmission system (thus enabling independent and flexible control). So, load distribution between central and side propellers could be optimized. The main advantage of this arrangement is a possibility to draw nominal power for particular convoy or maneuvering barge configuration.



Loa = 24.2 m
B= 11.4 m
H = 2.8 m
T = 1.9 m
Diesel eng. of 2 x 600 kW/1800 rpm
Nominal propeller power 960 kW

Fig 4.7 Hybrid pushboat (project)

According to (Bilen and Zerjal 1998) there are several advantages of proposed hybrid pushboat (in the first place, flexibility in operation and elimination of propeller shafts and main and flanking rudders), which can overcome a well known disadvantage of hydrostatic pod propulsors (their low efficiency). Nevertheless, hydraulic transmission could be replaced by an electric transmission with electric pod propulsors, which have higher efficiency. Of course, this would not alter the innovative approach presented by hybrid pushboat design.

Concerning the electric propulsion, an Austrian river icebreaker "Roethelstein" built in Kvaerner-Masa Yards in Helsinki, for Oesterreichische Donau Kraftwerke AG, with Azipod propulsion should be mentioned, see Fig. 4.8 (Ship & Boat Int. 6-1995). On the trials Roethelstein proved capability of penetrating 4 m thick ice ridges and breaking 0.7 m level ice at the speed of 1.5-2 km/h. The hull form follows current thinking for very shallow draught icebreakers with cylindrical bow, parallel mid body and underflow stern feeding water to the podded azimuth propulsion units (see Fig. 3.9). Of course, Roethelstein is of great interest because of its propulsion system, which is the application of the Azipod principle to small power.

Loa = 42.3 m
B_{MAX} = 10.3 m
H = 3.35 m
Air draught = 6.05 m
T = 2 m (can operate with 1.6 m)
Bollard pull = 125 kN
Speed = 20 km/h
Main engines = 2 x 700 kW/1500 rpm
Rudder propeller 2 x 560 kW/550 rpm

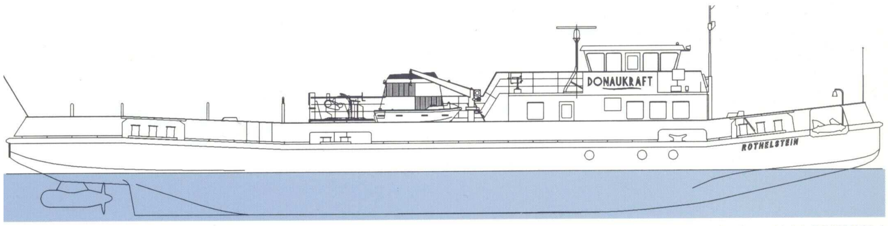


Fig. 4.8 River ice breaker with Azipod propulsors

4.2 Some Selfpropelled Vessels

Selfpropelled bulkcarriers "Sava Mala" and "Dorcol" (Fig. 4.9) built for the Ivan Milutinovic Company, are among the largest on the Danube. Their capacity is 2600 t of bulk cargo.

Loa = 96.5 m
B = 13.8 m
H = 3.4 m
T = 2.9 m
PB = 2 x 330 kW

Fig. 4.9 Selfpropelled, self-discharge river bulkcarrier

Their unique self-discharge equipment (powered by two Diesels of 365 kW) is designed to handle any bulk cargo, but vessels are mainly used for gravel and sand transport. Two large buckets which move longitudinally feed the cargo to transversal transfer conveyer (reach 34 m) enabling self-discharge to shore or a hold of another vessel. Furthermore, to increase the capacity, high tensile steel was used for coamings and gangways, so the vessels are relatively elastic with unusually large sagging of around 25 cm.

Cement carrier “Sajkas” (Fig. 4.10) built for the Heroj Pinki Company have capacity of 1500 t. Vessel was originally built with 18 cylindrical cement-holds and special pneumatic self-discharge equipment, but soon after the launching, although in many respects a remarkable vessel, she was reconstructed into ordinary bulk carrier. The reason for this was that adequate shore capacities for cement acceptance were never built!

Loa = 102.0 m
B = 11.6 m
H = 3.5 m
T = 2.3 m
PB = 2 x 300 kW

Fig. 4.10 Vessel “Sajkas” as a cement carrier

Two selfpropelled bulkcarriers named “Lajkovac” and “Doboj” (whose plans for reconstruction into the Ro-Ro vessel are shown in Fig. 2.13 and 2.14) were reconstructed into special three-deck car carriers. Simultaneously four barges were also reconstructed to three-deck car carriers and were equipped with hydraulically operated bow ramp. A coupling train consisting of a selfpropelled vessel + 2 barges suppose to transport 500 Lada cars, from Soviet Union to former Yugoslavia. Unfortunately, these vessels were never used for this purpose, except “Lajkovac” on the Upper Danube for a short period of time in mid nineties.

5. CONCLUDING REMARKS

5.1 Conclusions

Some of the conclusions, given in the order of appearance, follow:

a) Main infrastructure bottlenecks that are problematic for the navigation (Section 1.1):
- Stretch Straubing-Vilshofen (Danube km 2324-2249) with depth by LNRL of 2.0 (1.7) m only and air clearance over HWL of 4.73 m.
- Pontoon Bridge at Novi Sad is a temporary obstacle (presently opens three times a week) which will be removed as soon as the new bridge is finished (expected by 2005).

b) Vessels should be designed – matched – according to the waterway characteristics. In the context of this WP, only subcritical region is of interest (Section 1.2.4).

c) Under the condition the container transport technology is widely accepted in the Danube corridor, as well as that sufficient quantity of cargo is in the intermodal (container) transport (which is presently not the case), selfpropelled container vessels should be designed for a draught of 2.5 m (three container layers) with the possibility of sailing at reduced draught of 1.5 – 1.7 m with only two container layers. Suggested beam should be 11.4 (11.45) m (four containers abreast), while the length is practically unrestricted (but most probably should be below 110 m). Propeller diameter of 1.4 – 1.5 m should be considered (Section 2.1, particularly 2.1.8).

d) Selfpropelled Ro-Ro vessel should be designed for relatively small draught of 1.4 – 1.5 m, beam of less than 23.4 m (for sailing up to Regensburg) and a length of up to 135 m. Preference is given to unaccompanied, point-to-point service. Smaller vessels should also be taken into consideration (Section 2.2).

e) Over a short and probably a medium term, the preference is given to the implementation of Ro-Ro rather than to container transport (Section 2.2.4).

f) The use of (standardized) push trains and coupling trains are recommended if larger quantities of cargo are considered. The shallow draught problems might be overcome with partly loaded barges (Section 2.3).

g) Already developed contemporary technologies which might be applied on the Danube vessels in much greater extent, concerns (Section 3):
- The new ship forms (Section 3.1.1)
- River information services – RIS (Section 3.4)
- Propulsors with higher efficiencies which also enable enhanced maneuverability (Section 3.2.1)
- New generations of cleaner Diesel engines (Section 3.3.1).

Promising new technologies that might be applied in the future are:

- Sandwich plate system (Section 3.1.2)
- Electrical transmissions with pod and tip-driven (rim-driven) electro-motor propulsors (Section 3.2.1)
- Fuel cells (Section 3.3.2).

h) The Danube fleet, with exception of a very small percentage of vessels, is old and outdated (Section 4).

Some vessels/ship components/services mentioned in DoW are not applicable on the Danube (as on the Rhine and its tributaries) – for instance, the pallet carriers – so, these subjects were not elaborated by WP in sufficient extent. Furthermore, in some cases adequate explanation is given in the DoW itself.

5.2 Brief Answers to Four Key Questions Treated by the WP

1) What is the most promising ship technology/innovation (from the point of view of intermodal transport) ?

Taking into account present reality along the Danube corridor: a) The Upper Danube regions with well developed but congested roadway and railway infrastructure, and b) Middle and Lower Danube regions with undeveloped, ruined and neglected roadway and railway infrastructure and with the river transport potentials (ports, fleet, etc.) in the transition phase,

- The Ro-Ro technology is considered to be the most promising, giving immediate intermodal transport solution for exchange of goods between CEC and SEEC.

- Container transportation on the Danube is still in the evolution phase. Nevertheless, an expansion will start from both Danube’s ends:
  - Developed Germany and Austria on the Upper Danube, and
  - Well-positioned seaport of Constantza on the Lower Danube.

2) Which of these innovations have already been (or are expected to be) realised ?

First generation of Ro-Ro vessels already exists on the Danube. The commercial success of these vessels is well known (in spite of various obstacles present on the Danube waterway and in the Danube corridor during the last decade). Nevertheless, the second generation of Ro-Ro vessels should implement some new innovations developed during the last twenty years, as well as the experience gained during the exploitation of already existing vessels. Among already developed technologies which might be implemented immediately are RIS, more efficient propulsors, cleaner Diesel engines etc. It should be noted, however, that newly built vessels and consequently the innovations, proceed relatively slowly on the Danube.

3) Which of the promising innovations were not commercially successful ?

Among commercially non-successful innovation (from the point of view of intermodal transport), the DCS container service Deggendorf-Enns-Budapest, initiated in 2001, is worth mentioning. Planned capacity was 20.000 TEUs per year, while for nine months of operation less than 1500 TEUs was transported. Abovementioned regular container line was even planned to be extended to Belgrade, but at the beginning of 2002 was closed. Besides the financial and organizational difficulties (probably expected for newly opened service), insufficient penetration of the regional markets should also be mentioned.

4) Policy recommendations – Suggestions for a common European strategy

The recommendations already mentioned in SPIN-Rhine are, naturally, valid for the Danube too. Nevertheless, two additional groups of measures – recommendations - should also be mentioned:

- General knowledge, understanding and awareness concerning the potentials of river transport and benefits of intermodal transport should be improved. Disadvantages of long distance road transport along the Danube corridor, combined with the problems of passing through the Alps, should be highlighted. Forwarders and road transporters should be instructed in advance which administrative measures (taxation and restrictions) will be introduced in short and mid term future.

- Fleet modernization and renewal are recommended; this should be followed with the scrapping policy of old vessels. In other words, the *old-for-new* regulations - somewhat controversial measure in many aspects but promoted by the European Commission for the EU member states - should also be extended to the Danube. This would improve the productivity of the sector and would also be spiritus movens for the Danube shipyards and related industries.

NOMENCLATURE AND ABREVATIONS

B – Beam
C_c – Coefficient of container transport efficiency
D – Propeller diameter
F_{nL} – Froude number based on waterline length
F_{nh} – Froude number based on water depth
L - Vessel length
T - Vessel draught
h - Water depth
g – Gravitational acceleration
P_B - Installed power
v - Vessel speed
R_T – Total resistance
η_D – Propulsive efficiency
η_S – Shaft efficiency
R_{Th} – Total resistance in shallow water
R_w – Wave making resistance
R_v – Viscous resistance
$R_{T\infty}$ - Total efficiency in deep water
r – Resistance ratio ($R_{Th}/R_{T\infty}$)
H – Vessel depth
m_c – Container mass
n_H – Number of container layers
n – Number of containers onboard
dwt – Deadweight

GRP – Glass Reinforced Plastic
SPS – Sandwich Plate System
FPP – Fixed Pitch Propeller
CPP – Controllable Pitch Propeller
CRP – Contra Rotating Propeller
SPP – Surface Piercing Propeller
IMP – Integral Motor Propeller
RDP – Rim Driven Propeller
FC – Fuel Cells
Ro-Ro – Roll on - Roll off
Lo-Lo – Load-on Load-off
Ro-La – Road-Rail combined transport
MMPO – Modular Multi-Purpose Vessel

LNRL - Low Navigation and Regulation Level
HWL - High Water Level
TEU – Twenty feet Equivalent Unit
CEC – Central European Countries
SEEC – South East European Countries
IW – Inland Waterway
SPIN – European Strategies to Promote Inland Navigation
WG – Working Group
WP – Work Package
DoW – Description of Work
COVEDA – COntainer VEssels for the DAnube waterway
EUDET – Evaluation of the Danube Waterway as a Key European Transport Resource
ITTC – International Towing Tank Conference
MUTAND – Multimodal Ro-Ro TrANsport on the Danube river
GL – Germanischer Lloyd
ADNR – Réglement pour le transport de matières dangereuses sur le Rhin
INBISHIP – Common European Inland Vessel Concept
IMO – International Maritime Organisation
R&D – Research & Development
EST – Environmentally Sustainable Transport
ETA – Estimated Time of Arrival
RIS – River Information Services
ECDIS – Electronic Charts Display Information Service

ELWIS – Electronical Waterway Information System
DORIS – Donau River Information Services
ALSO Danube – Advanced Logistics Solutions on the Danube River
COMPRIS – Consortium for an operational Management Platform for RIS
CRORIS – CROatian River Information Services
YURIS – YUgoslav River Information Services

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