ENVIRONMENTALLY FRIENDLY
INLAND WATERWAY SHIP DESIGN
FOR THE DANUBE RIVER

World Wide Fund for Nature International
Danube-Carpathian Programme
(WWF-DCP)

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ABBREVATIONS, ACRONYMS and NOMENCLATURE

Abbreviations

ADN	– European agreement concerning the international carriage if dangerous goods in IWT
ADN-D/ ADN-R	– Carriage of dangerous goods on the Danube/Rhine
AIS	– Automatic Identification System
ATM	– Advising Tempomaat
BD	– Biodiesel
BDB	– Biodiesel Blend
CEC	– Central European Countries
CCNR	– Central Commission for the Navigation on the Rhine
CPP	– Controllable Pitch Propeller
CRP	– Contra Rotating Propeller
DG TREN	– European Commission, General Directorate for Energy and Transport
DM Canal	– Danube-Main Canal
DPC	– Danube Project Centre, Belgrade
DST	– Development Centre for Ship Technology and Transport Systems (VBD), Duisburg (DE)
ECDIS	– Electronic Chart Display and Information System
ECE	– United Nations Economic Commission for Europe
EE	– East European
EILU	– European Intermodal Loading Unit
EPA	– Environmental Protection Agency (United States)
ERT	– Emission Reduction Technologies
EST	– Environmentally Sustainable Transport
ESTR	– Equivalent Semi-Trailers
ETA	– Estimated Time of Arrival
FC	– Fuel Cell
FEU	– Forty feet Equivalent Unit (ISO 40’ container)
FPP	– Fixed Pitch Propeller
GL	– Germanischer Lloyd
GMS	– Grossmotorschiff
GRP	– Glass Reinforced Plastic
HWL	– High Water Level
ILU	– Intermodal Loading Unit
IMP	– Integral Motor Propeller
INE	– Inland Navigation Europe
ISO	– International Standard Organization
IT	– Information Technology
ITTC	– International Towing Tank Conference
IWT	– Inland Water Transport
JRB	– Yugoslav Shipping Company
IWW	– Inland Water Way
LNG	– Liquefied Natural Gas
LNRL	– Low Navigation and Regulation Level
Lo-Lo	– Load-on – Load-off
LR	– Lloyd’s Register

LSF	– Low Sulphur Fuel
MARIN	– Maritime Institute of Netherlands, Wageningen
NGE	– Natural Gas Engine
O/D	– Origin – Destination
PIANC	– Permanent International Association of Navigation Congresses
PMF	– Particulate Matter Filter
RCD	– Recreational Craft Directive (United States)
RDP	– Rim Driven Propeller
RIS	– River Information Services
Ro-La	– Road-Rail combined transport
Ro-Ro	– Roll-on – Roll-off
SCR	– Selective Catalytic Reduction
SEEC	– South East European Countries
SES	– Surface Effect Ship
SPP	– Surface Piercing Propeller
SPS	– Sandwich Plate System
SWL	– Safe Working Load
TEN	– Trans European Network
TEU	– Twenty feet Equivalent Unit (ISO 20’ container)
ToR	– Terms of Reference
VBD	– Versuchsanstalt fur Binnenschiffbau e.V. Duisburg (now DST), Germany
WEC	– West European Countries
WP	– Work Package
WWF	– World Wide Fund for Nature

Project’s Acronyms

COMPRIS	– Consortium for Operational Management Platform for River Information Services (FP5 Project)
COVEDA	– Container Vessels for the Danube waterway (DPC Project)
CREATING	– Concepts to Reduce Environmental impact and Attain optimal Transport performance by Inland NaviGation (FP6 Project)
EUDET	– Evaluation of the Danube waterway as a key European Transport resource (FP4 Project)
INBAT	– Innovative Barge Train (FP5 Project)
INBISHIP	– New Opportunities for Inland Waterway Transport (BRITE EURAM Project)
KLIWAS	– Consequences of climate change for navigable waterways and options for the economy and inland navigation (National German project)
MUTAND	– Multimodal Ro-Ro Transport on the Danube river (DPC & DST project)
PASCAT	– Partial Air cushion Supported Catamaran (GROWTH Programme)
PELS	– Project Energy-saving Air-Lubricated Ships (National Dutch research project)
SMOOTH	– Sustainable Methods for Optimal design and Operation of Ships with air lubricaTed Hulls (FP6 Project)
SPIN	– Strategies for Promoting Inland Navigation (GROWTH Programme)
VEBIS	– Improvement of the efficiency of inland water transportation (German Project)

ELWIS, DORIS, ALSO Danube, CRORIS, YURIS – National RIS projects

Nomenclature

B	– Vessel beam (m)
c_T	– Train formation coefficient ($R_T/\Sigma R_i$)
C_C	– Coefficient of container transport efficiency (no. containers·km/h / kW)
dwt	– Deadweight (t)
D_P	– Propeller diameter (m)
F	– Freeboard (H-T) (m)
F_{Nh}	– Froude number based on water depth ($v/\sqrt{(g \cdot h)}$)
F_{nL}	– Froude number based on waterline length($v/\sqrt{(g \cdot L)}$)
g	– Gravitational acceleration (m/s^2)
h	– Water depth (m)
$h_{W\text{-}LNRL}$	– Water depth by LNRL (m)
$h_{A\text{-}HWL}$	– Air clearance over HWL (m)
H	– Vessel height or depth (m)
L	– Vessel length (m)
m_{lig}	– Lightship mass (t)
m_c	– Container mass (t)
n	– Number of containers onboard
n_H	– Number of container layers
P_B	– Installed power (kW)
P_D	– Delivered power (kW)
r	– Resistance ratio ($R_{wh}/R_{w\infty}$)
R_i	– Individual resistance of each barge (kN)
R_T	– Total resistance (kN)
R_v	– Viscous resistance (kN)
R_w	– Wave making resistance (kN)
T	– Vessel draught (m)
v	– Vessel speed (km/h)
η_D	– Propulsive efficiency
η_S	– Shaft efficiency

Subscripts

h	– Finite water depth (shallow water)
∞	– Infinite water depth (deep water)
OA	– Overall

0. METHODOLOGY

Introductory part (Sections 2, 3 and 4)

First, as an introduction, restrictions of the Danube waterway (and its tributaries) are given, as restrictions in water depth, lock size and bridge heights dictate main ship dimensions. This is followed by sections (probably complicated to a non-technical reader) on shallow water hydrodynamics which is important for design and operation of every vessel intended to navigate in inland waterways. Basic knowledge about transhipment possibilities, intermodal loading units, logistics and associated problems is also essential as these influence ship design.

Waterborne transport (Sections 5 and 6)

Waterborne transport is in the focus of this study, so state-of-the-art of selfpropelled vessels and barge trains follows. Special attention is given to design of selfpropelled container vessels for the Danube waterway (Section 6) as they, per se, actually do not exist (like on the Rhine).

Measures to make inland ships cleaner and more efficient (Section 7)

A discussion follows on ship components (propulsors, machinery, etc.) and achievements that lead to fuel-efficiency; this is important for the design of innovative Danube vessels. These are recent achievements in ship resistance, propulsion, engines, construction and ship utilization. Some of the achievements that are mentioned will be implemented in the designs of proposed concepts for the Danube (given in Section 8).

Proposed concepts for the Danube River (Section 8)

Finally, the report gives a section on design of concepts for container and bulk cargo transport. These concepts fulfil contemporary ecological demands, apply innovative technologies, and obey the existing waterway restrictions explained above. The designs proposed are a selfpropelled vessel for container transport and barge train for bulk cargo transport.

Appendices

Topics treated in the appendices give some extra information useful for the subject.

Several parts of this report originate from other studies and papers that were written or co-written by the author of this study (namely, SPIN, CREATING, COVEDA etc.). In the parentheses, after each section title, references are given from where most of the text/material originates from. Consequently, references are given wherever necessary, except in cases explained above.

1. TERMS OF REFERENCE

The most important items of the Terms of Reference (ToR) are:

- Information on shallow draught ship technology is needed to fine tune WWF's arguments and position in inland navigation on the Danube.
- Knowledge on inland navigation and innovative ship designs that provide technically and economically feasible alternatives to present concepts and technology should be given.
- Proposed solutions should be in harmony with present ecological demands, i.e. should require less or no new infrastructure/river modification that negatively impacts river ecosystems and dynamics.
- Technical solutions should be proposed that adapt ships to the Danube River, in particular to the shallow sectors on the Lower Danube, but that are also able to operate on the Danube tributaries and Danube-Main Canal.
- Transport of container and bulk cargo should be considered; attention should be paid to upgrading/retrofitting present vessels and to the new ships.

2. INTRODUCTION [SPIN, COVEDA]

2.1. What is an optimal IWW ship?

There are several definitions of optimal ship, one of them, according to Zigic (2008), define optimal ship as:

- Modern and environmentally friendly
- With low exhaust emissions
- With low fuel consumption
- Economical in operation
- Highly compatible with the waterway
- Have capability to align to the river
- Have minimal impacts on bank vegetation and fish fauna.

Allowed water depth, that changes along the river and during the season, should be specially analysed as it influences transport performance through ship carrying capacity and speed (see Figure 2.1).

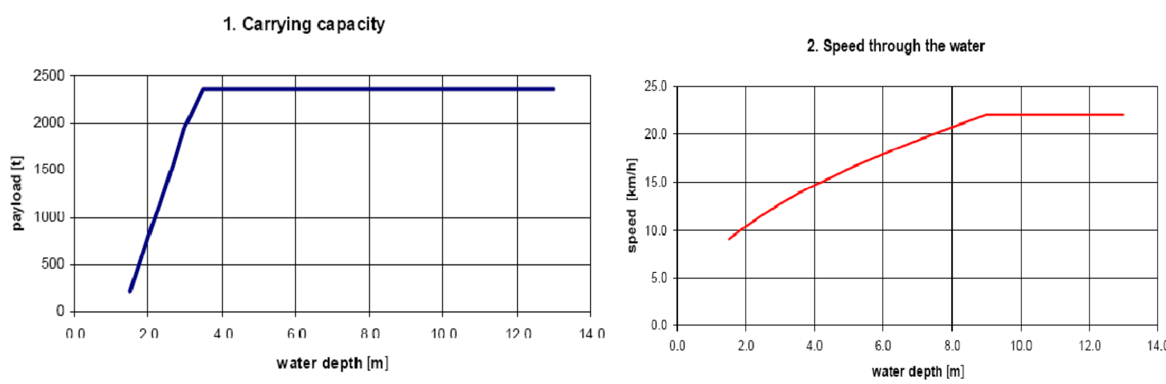


Figure 2.1 Influence of water depth on ship payload and speed (Source: Zigic, 2008)

Operational costs are dramatically reduced with increase of water depth, i.e. increase of vessel draught. Nevertheless, during the low water levels, the ship should be able to operate with restricted economical effects. The same ship should be able to operate in deeper water too, but will then be less efficient than the ship initially designed for deep-water operation only. Extremely shallow water, however, is often regarded as severe operational conditions. Therefore, transport costs, however calculated, are very much influenced by water depth.

All transport modes to greater or smaller extent have some negative impacts on water, air, soil biotic balance, climatic conditions, health, and economy, to name a few. Amongst them, IWT seems to have the least effects that can be quantified, for instance through direct and indirect costs (see Appendix 6, and leaflets on Environment and Sustainability by INE - www.inlandnavigation.org and Power of Inland Navigation by BVB). Direct costs are more or less obvious, but indirect costs are somehow hidden and difficult to quantify. There are other impacts which are even more difficult to quantify, for instance accidents, congestion, impacts on humans, flora and fauna etc. An optimal ship, therefore, should cause the least impacts that are mentioned above. This can be achieved by a) applying contemporary design measures, and b) through making design compromises (sometimes it is necessary to sacrifice/reduce cost-effectiveness to obtain an overall good and environmentally acceptable vessel).

2.2. Importance of the waterway

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 differ mainly in the abovementioned – the Rhine is deeper and regulated (which, however, requires many investments into fairway maintenance) while the Danube, although much longer and wider, is relatively shallow and unregulated river with large variations in water depths. Consequently, the main difference between Rhine and the Danube vessels is their draught, which has very important consequences on several other ship parameters.

Furthermore, the Rhine passes through the most developed part of Europe, probably the world, so it is quite normal that several technical solutions applied on the Rhine vessels are copied/transferred to other river vessels, in this particular case to the Danube vessels. However, it should be underlined that often it is not possible to copy/transfer every service or technical solution due to the already-mentioned waterway differences. Other differences are also important, for instance hinterland and infrastructure development along the Rhine and the Danube corridor (see Section 4.3), which actually dictate volume and type of cargo, transhipment facilities, intermodal loading units etc.

2.3. Restrictions of the Danube waterway (with its tributaries)

Characteristics of inland vessels for the Danube waterway depend very much on the waterway itself, i.e. its depth, height of the bridges and size of locks. Therefore, the main characteristics of the Danube waterway and its tributaries should be stated here (see Figure 2.2).

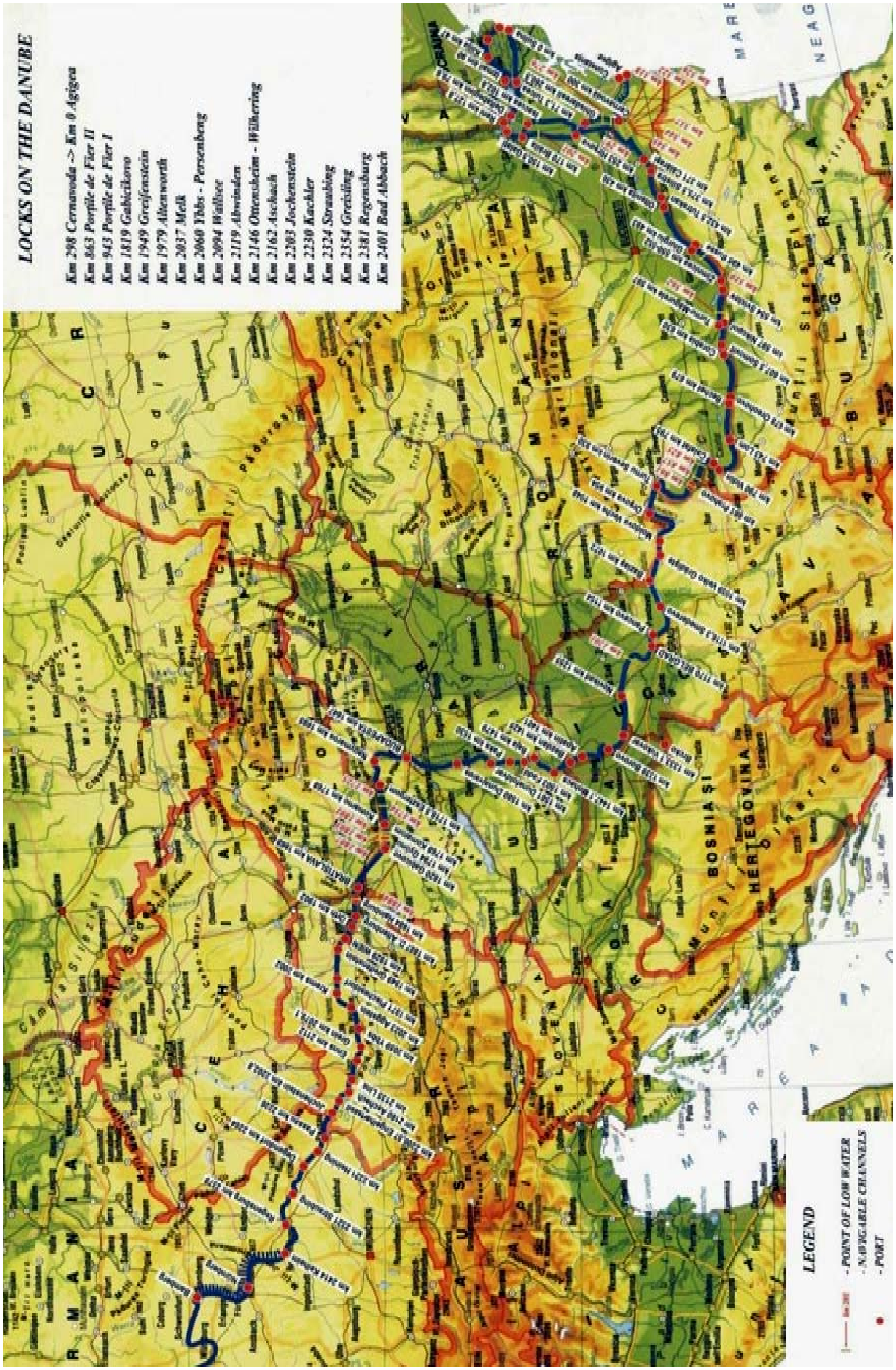


Figure 2.2 Locks and ports on the Danube (Source: TTS Group)

2.3.1. The Danube

According to its physical and geographical characteristics, the river Danube is 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 2.1). The EUDET Project showed, however, that such division is partly out of date, and proposed a new division of the Danube, which differentiate the canalised (articulated) sections 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, waterway statistics are 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 2.2 an attempt is 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 implement them to the EUDET division of the Danube waterway. Numbers in brackets indicate that different data were found in the references.

Table 2.1 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 Veche	1048	Drobeta	931
Lower Danube – Sector III				
III-1	Drobeta	931	Braila	170
III-2	Braila	170	Sulina	0

* 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.

Table 2.2 The EUDET division of the Danube with 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 – Durnstein	2038 – 2008	VIb	free-flowing (shallow)	2.3 (2.5)	6.65	
Durnstein – 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		

Note: Navigability of the fairway is also influenced by the natural profile of a watercourse - thalweg (river path with maximum depth and/or velocity).

2.3.2. Some critical points on the Lower Danube

In order to improve navigation conditions, necessary water depth, width and minimal curve radius according to the Danube Commission recommendations should be at least 2.5 m, 150-180 m and 1000 m respectively. Nevertheless, due to various reasons water depth on several sectors, and in particular on some Lower Danube sectors, is less than recommended. Just one example of critical sectors (identified by the EU's TEN-T Programme) are:

- Danube km 375 to 175 (Calarasi – Braila), and
- Danube km 531 to 521 (Batin sector).

Amongst these, the Danube between km 346 and 300 (Bala Branch outlet to Black Sea Canal outlet at Cernavoda, Figure 2.3) is particularly critical for navigation during the dry seasons, with water depth on some sectors of around 1.5 m only. Consequently, ships often have to use a detour – via Bala-Borcea Branch – which increases navigation length to the Black Sea Canal for around 110 km. Moreover, one way navigation and convoy dismantling is often necessary in the Borcea Branch.

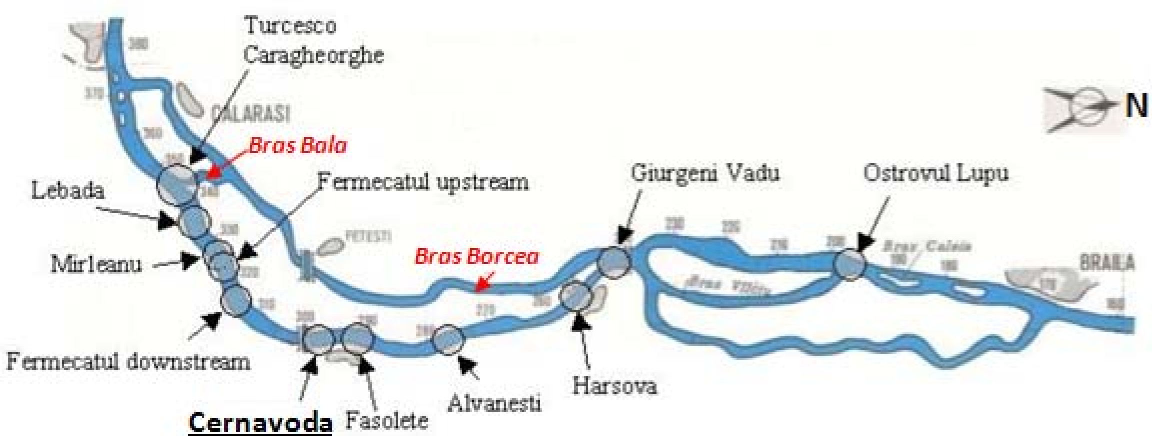


Figure 2.3 Critical points on Calarasi-Braila sector (Source: ISPA)

2.3.3. 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 2.3. Since the tributaries have a much lower class than the Danube, allowed vessel dimensions are also depicted in Table 2.3. The Rhine-Main-Danube waterway is shown in Figure 2.4.

Table 2.3 Navigable tributaries and canals of the Danube
(Source: Manual on Danube Navigation)

No.	Name	Danube estuary [river-km]	Section	Waterway Classification	Length [km]	Width[1] [m]	Draught [m]	Height [m][2]	Number of Locks
1	Drava	1,382.5 right bank	km 198–km 68	II	130	6.6	1.4	3.0	0
			km 68–Osijek	III	46	8.2	1.9	4.0	0
			Osijek–Danube	IV	22	11.4	2.5	5.3	0
2	Bogojevo–Bečej–Canal	1,363.4 left bank	Bogojevo–Bečej	III [3]	90	11.0	2.15	6.2	3
3	Novi Sad–Savino–Selo Canal	1,253.5 left bank	Savino-Selo–Novi Sad	IV	39	11.4	2.5	12	1
4	Tisza	1,214.5 left bank	Vasarosnameny–Tisazalök	II	177	7.0	2.5		0
			Tisazalök–Danube	IV	519	9.5	2.5		3
5	Bega	Tisza estuary at km 10 right bank	Tisza–km 35	III [3]	35	11.4	2.15	5.6	1
			km 35–km 64	III	29	9.5	2.0	5.4	2
6	Sava	1,170 right bank	Sisak–Šamac	III	281	8.2	2.0	4.0	0
			Šamac–Belgrade	Va	306	11.4	2.5		0
7	Palanka–Bečej–Canal	1,076.5 left bank	Palanka–Bečej	III [3]	147	11.0	2.15	5.6	3
8	Cernavoda–Canal	299.5 right bank	Cernavoda–Constanta	VIc	60	22.8	5.5	17.0	2

[1] *Permissible width of vessel or pushed convoy*
[2] *Minimum air clearance of bridges*
[3] *Due to draught limitations, only waterway class III; the remaining parameters meet the requirements for waterway class IV*

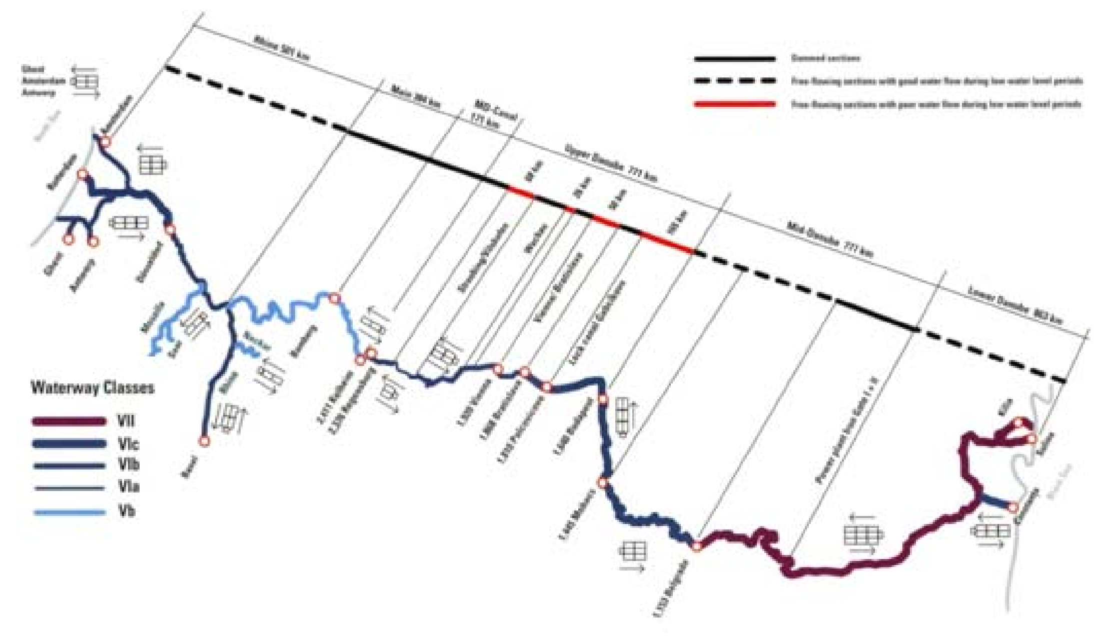


Figure 2.4 Rhine-Main-Danube Waterway (Rotterdam-Sulina 3467 km)
(Source: Manual on Danube Navigation)

2.3.4. Impact of climate change on Danube navigation

It is difficult to estimate possible impacts from the climate change on Danube navigation. According to “Prospects on the development of infrastructure and navigation on the Danube”, in the future there will probably be more periods of intense rainfall (danger of high water), but also more and longer arid periods.

According to a recent PIANC Report (see Appendix 2), shipping companies try to respond to the phenomena of low water levels and floods in a way that it assures the reliability of inland navigation through “adaptation of the fleet and new vessels of different design” as well as “light loading of current vessels and use of vessels with decreased draught”. Increased and decreased water levels (and therefore water velocities too); change in timing of seasonal high and low water and shorter duration of river ice also demand better manoeuvring capabilities of ships. The Federal Institute for Hydrology of the German Ministry of Transport is presently funding project KLIWAS, whose purpose is to develop a sound statement about the span of possible climate changes. In the same context see also proceedings of recent conference *Rhineschifffahrt und Klimawandel.*

2.4. Concluding remarks

Water depth

a) On the Upper Danube the most critical stretch is between Straubing and Vilshofen with $h_{W\text{-}LNRL} < 2$ m (according to some statistics even 1.7 m).

b) Several sectors on the Upper Danube (upstream to Budapest) have $h_{W\text{-}LNRL} = 2.0 – 2.3$ m.

c) A few sectors on the Lower Danube (downstream of Iron Gates II) have $h_{W\text{-}LNRL} = 2.3 – 2.4$ m. According to some statistics water depth on critical sectors is as low as 1.5 m, so detour via other (longer) routes is necessary (Figure 2.3).

d) Elsewhere, $h_{W\text{-}LNRL} > 2.5$ m. On the Middle Danube the depth is often over 5 m.

Bridge height or air clearance

The most critical bridge heights are again on the Upper Danube, i.e. the bridges in Deggendorf and Passau with $h_{A\text{-}HWL} = 4.73$ m and 6.36 m, respectively. The height of RMD canal bridges is around 6 m. All other bridges upstream from Budapest are around 6.7 m. Downstream from Budapest $h_{A\text{-}HWL} > 7.5$ m.

Size of locks

Most of the Danube locks have standard European dimension. The most critical one is upstream of Straubing at 12 x 190 m (as all locks of RDM canal), while the rest on the Upper Danube are 2 x 24 x 190 m. The locks built by ex-East-European Countries are even 2 x 34 x 275 (310) m (see Figure 2.5).

Figure 2.5 Djerdap 1 lock (Serbian side) full and empty (Source: Witteveen – Bos)

Implications on ship design

Taking into account that a) an IWW vessel should be designed according to the particular waterway, and b) that all-around clearance between the vessel (or her cargo) and bridge/river-bottom/lock-side should be at least 0.3 m, the maximal allowed vessel dimensions, with possible minor restrictions in sailing during the dry seasons, are

- For the whole Danube including the stretch upstream of Straubing-Vilshofen, as well as through the DM Canal: $T < 1.7$ m (probably 2 m), $B \leq 11.45$ m.
- Downstream of Vilshofen: $T < 2.0$ m (probably 2.5 m), $B \leq 23.4$ m.

The length of self-propelled vessels is practically unrestricted, while coupling train formation will be discussed later (see Tables 2.2, 2.3 and 5.1). The air draught depends on the bridges (see Tables 2.2 and 2.3).

3. BASIC APPROACH TO INLAND VESSEL HYDRODYNAMICS [SPIN]

Fuel consumption depends on power needed for propelling the vessel with a certain speed (neglecting the consumption of generating sets and other minor consumers on board). Various 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 speed (v), resistance (R_T) and efficiency of the propulsors (η_D). In particular

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

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

3.1. Shallow water resistance

Shallow water hydrodynamics is of primary importance for inland vessels and particularly for fast inland vessels. In shallow water, vessel resistance is very much different than in deep water, and may play the most important role in inland vessel design (see power-speed diagram, Figure 3.1). Resistance R_{Th} shows a pronounced peak (resistance increases) at the critical Froude number (critical speed which depends on water depth). This may be explained with the growth, which is then followed by the loss, of transverse waves. So, although in the expression above the total resistance R_T was mentioned, in the shallow water only one resistance component – the wave making resistance R_W – changes dramatically (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:

- <u>sub-critical</u> region where the effects of water depth are almost negligible

- <u>critical</u> region where R_{Wh} increases dramatically (r is greater than 1)

- <u>super-critical</u> region where R_{Wh} may be smaller than $R_{W\infty}$ (r is a bit smaller than 1).

The increase of wave-making resistance – resistance ratio r – in the critical region is of primary importance for fast vessels and depends mainly on the ratio of h/L (where L is vessel's waterline length). This is well depicted by a 3D diagram given in Figure 3.2 (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 Figures 3.3 and 3.4, indicate by gray scaling the critical region – black and dark-gray zones should be avoided. In Figure 3.4, $F_{nh} = v/\sqrt{(g \cdot h)}$ is the depth Froude number (relation between two Froude numbers is $F_{nL} = F_{nh}\sqrt{(h/L)}$). 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 speeds corresponding to $F_{nh} \approx$ 0.9-1.0, $F_{nL} \approx$ 0.3-0.4 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 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 deep water sea-going vessels). Note, however, that commercial vessels navigate at relatively low speeds in the sub-critical region (corresponding to F_{nh} < 0.6 - 0.7).

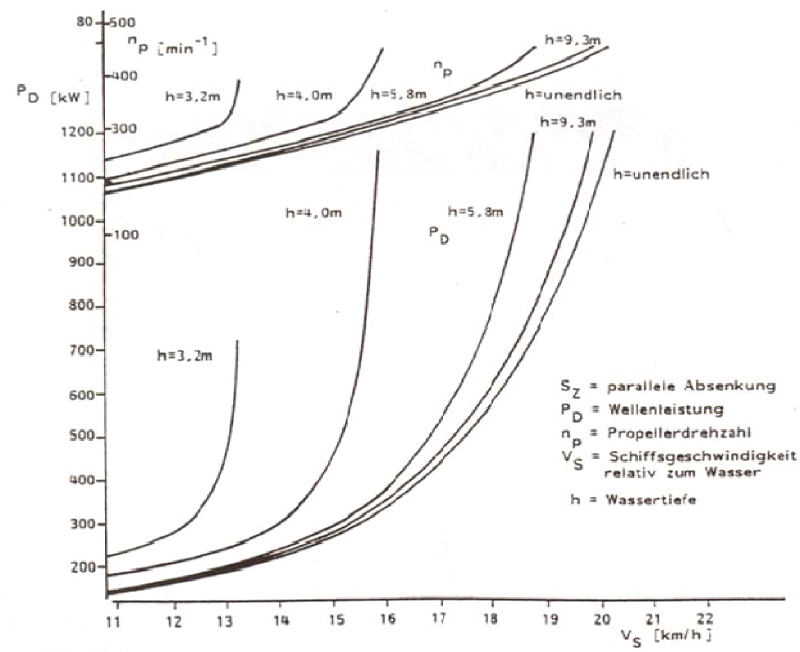


Figure 3.1 Power-speed diagram (sub-critical region) of a ship sailing in different water depths (Source: SPIN Rhine)

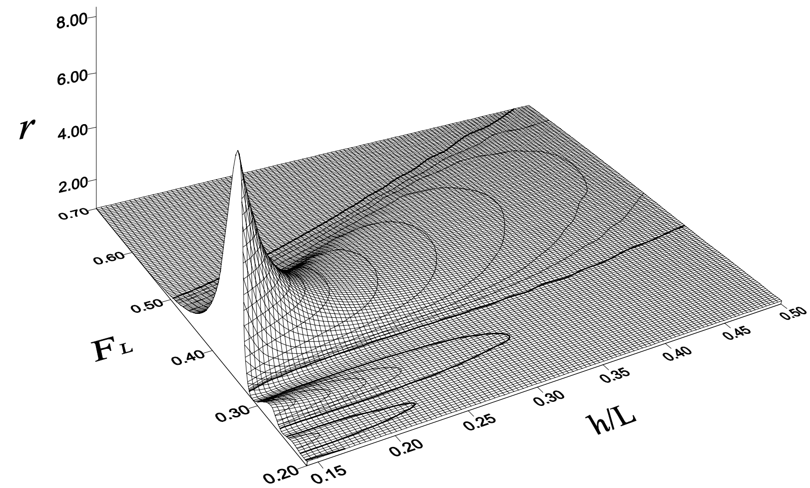


Figure 3.2 Shallow water resistance ratio

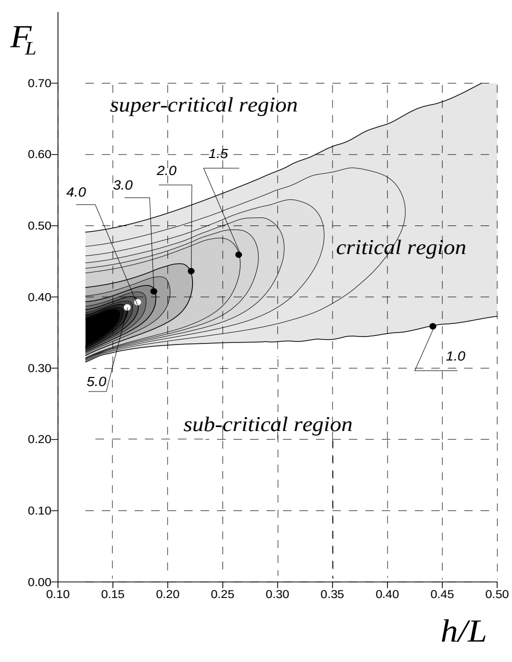


Fig. 3.3 Shallow water resistance chart

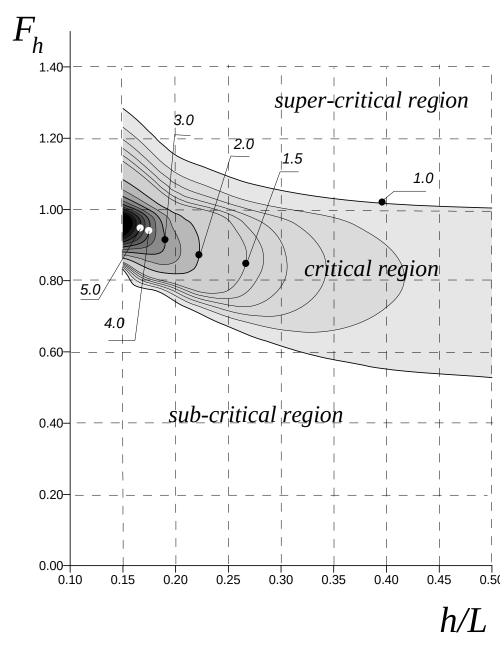


Fig. 3.4 Shallow water resistance chart

3.2. Propulsive efficiency in 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 regardless of water depth (i.e. transmission losses are usually 5%), only η_D is of further interest (η_D is the propulsive efficiency, also called quasi propulsive efficiency). Propulsive efficiency variations in shallow water are exactly opposite to 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 a 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).

3.3. 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-wash or just wash. The main wash problem is associated with the passage through a critical speed range and is particularly pronounced in shallow waters (see Figures 3.5 and 3.6). More about wave wash, and in particular about wave wash produced by high speed craft, is given in the Appendix 3.

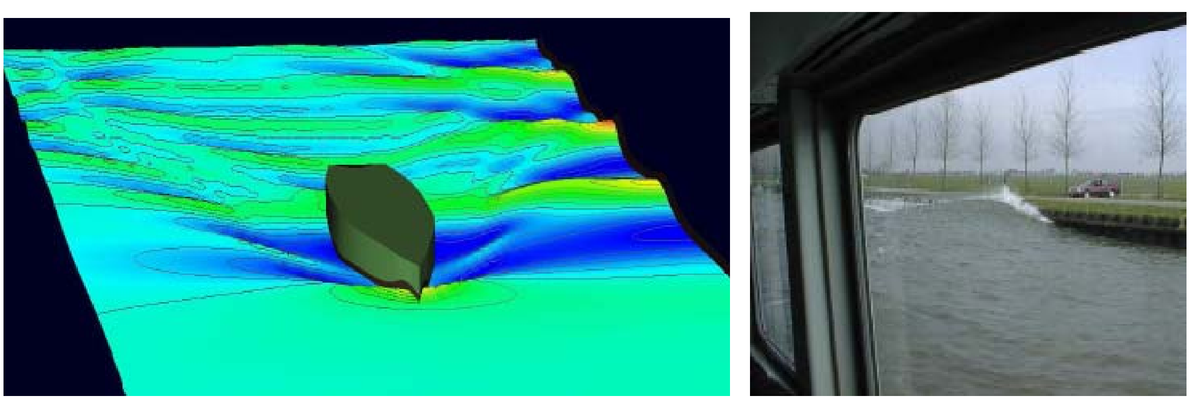


Figure 3.5 Typical shallow water wave system (Source: MARIN)

3.4. Concluding remarks

- Inland (shallow water) vessels should be designed (matched) according to waterway characteristics, i.e. the vessel's main parameters (draught, length, propeller size etc.) should be adjusted to the specific waterway.

- In the shallow water, three characteristic regimes exist (see Figure 3.6):

  Sub-critical (according to ITTC, below 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.

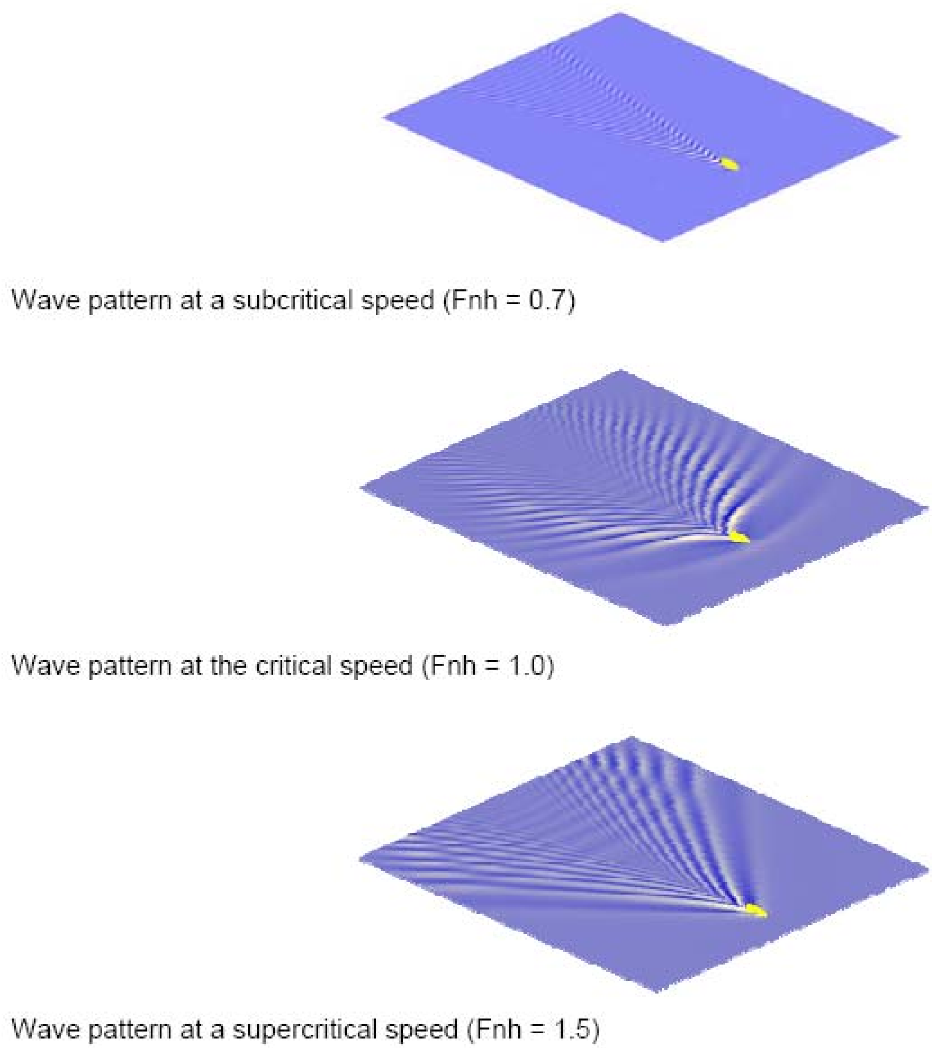


Figure 3.6 Changing of wave pattern of a ship moving at different speeds (Source: SPIN Rhine)

- 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 environmental reasons as well.

4. INTERMODALITY AND IWT [26th Duisburg Colloquium]

By definition, intermodal freight transport means the transport of goods in one loading unit, using two or more modes of transport successively, without handling the goods themselves. As such, intermodal transport has its main potential in long distance transport. Efficient use of intermodal transport also requires implementation of logistics - see Figure 4.1. (here, ISO containers and swap-bodies should be regarded, respectively, as stackable ILU and unstackable ILU – swap-body).

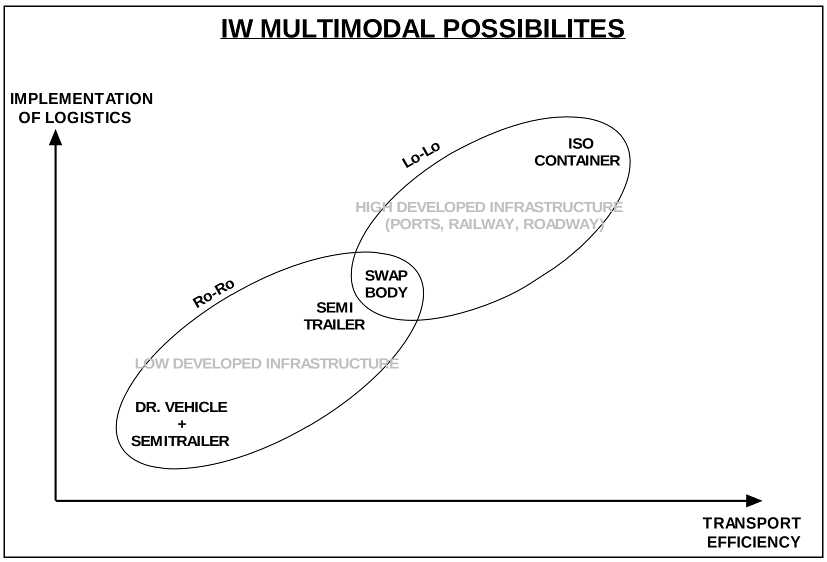


Fig. 4.1 IW multimodal possibilities

For intermodality that integrates IWT, the following links of the transport chain are generally necessary:

Door ---------------------- ***to*** ---------------------- ***Door***

⇓ ⇑

Land transport **Land transport**

⇓ ⇑

Transhipment ⇒ **Waterborne transport** ⇒ **Transhipment**

In both cases that are depicted in Figure 4.1 - Lo-Lo (container) technology and Ro-Ro technology - the first and last links (land transport) are more or less the same and are unavoidable. Therefore, further consideration in this study is limited to the rest of the transport chain, i.e. two transhipments and waterborne transport.

The Intermodal Loading Units (ILU) in IWT are containers, semi-trailers or swap-bodies. Consequently, the payload is the gross mass of loaded container, semi-trailer or a swap-body. However, for Ro-Ro vessels it is the deck area, not the mass of payload that is critical – in fact the key metric is the length of standard lane, i.e. it is the lane-meters that are sold. Thus, for Ro-Ro vessels the *payload* should be considered as *pay-area*, whereas the key parameter for the container vessel is the number of TEUs, i.e. the payload should be considered as *pay-volume*. In any case, proper relation between cargo space and cargo weight is of utmost importance; *well balanced ships* have a good ratio of cargo volume to cargo weight.

4.1. Transhipments and cargo handling equipment

As is well known, the transhipment of containers and other stackable ILUs to/from container vessels has to be done vertically (hence the abbreviation Lo-Lo for Load-on—Load-off), contrary to the horizontal transhipments (on wheels) of various kinds of cargo (Roll-on—Roll-off).

Lo-Lo transhipment of containers is efficient only if dedicated equipment is used, as for instance spreaders, expensive gantry cranes (for massive transhipment of containers), reach stackers (for smaller terminals), etc. Otherwise, transhipment will be relatively slow and therefore inefficient. Furthermore, for successful utilization of container technology it is often necessary to have transhipment equipment also at final destination and origin points in the hinterland, rather than just in the ports, with the necessary expertise and experience in use at all points. Non-stackable swap bodies are sometimes also transhipped vertically, by grappler arms (side-lift instead of top-lift). In that case some additional space between swap-bodies is needed. Further discussion about transhipment possibilities of various ILUs is beyond the scope of this study.

4.2. State-of-the-art of Intermodal Loading Units (ILU)

Stackable ISO containers - often called maritime containers – are assumed here and their 20 feet equivalent units (TEU) are 6.06 x 2.44 x 2.44 m (accordingly, 40 feet container is 12.19 m long). Other ILUs (domestic containers, swap-bodies, semi-trailers) are slightly wider - having 2.50 to 2.60 m outer width – and allow more pallets to be packed into them. That is, maritime containers have lower pallet capacity, ranging from 76% to 82% utilization, while the capacity of domestic containers ranges from 93-98%. It is expected that the share of stackable ILUs (swap-bodies) in European IW shipping will increase. This may amplify a deficiency caused by incompatible standards, i.e. the current standard-beam container vessels have maximal external beam of 11.45 m and maximal internal hold width of 10.10 m, such that four container layers abreast, each 2.50 m wide (max), could be stowed. But the majority of pallet wide ILUs are 2.55 m wide because packing of pallets into 2.50 m outer width ILUs is somewhat difficult. A feasible solution to this ship-hold-size vs. ILU-size problem could be mixed stowing of maritime containers (2.44 m wide) and ILUs (2.55 m wide). Also, increase of standard vessel beam from 11.45 m to 11.65 m is possible – but requires an acceptance of the recommended clearance between vessel and lock sides to be less than 0.3 m. European ILUs (EILU), which fulfil all requirements for compatibility with Euro-pallets, are stackable swap-bodies Class C 745 which are 7.45 x 2.55 x 2.90 m (longer type would be up to 45 feet long). By the way, presently the dominant European ILUs are swap-bodies that are not stackable.

Only the maritime containers (TEUs) are usually considered in IWT, although the most promising and dominant units in IWT in the next 20 or so years are expected to be both maritime ISO containers (for international deep-sea/overseas trade) and stackable, pallet-optimized long EILUs for intra-European trade – see “Current State of Standardisation and Future Standardisation Needs for Intermodal Loading Units in Europe” (www.cordis.europa.eu).

4.3. The hinterland

The industry and infrastructural development of the Danube hinterland are often neglected in the review of new transport projects, such as, for example, modal shift projects and intermodal transport. Furthermore, intermodal transport possibilities are often compared to those on the Rhine - although there is a striking difference between the Rhine and the Danube hinterland. The Rhine passes through the most developed parts of the world, while the development of the Danube hinterland varies, but is generally below that of the Rhine. The hinterland of the Upper Danube (Germany, Austria and partly Slovakia and Hungary) is generally well developed, while that of the Middle and Lower Danube is not. There are, however, some similarities between the Rhine’s Port of Rotterdam and the Danube’s Constanta (namely, around 1.5 million containers are presently transhipped through Constanta, with 36% increase in 2007 compared to 2006), but since the destination of this cargo is mostly for the area in the vicinity of Bucharest, the Danube as a whole, is not as well utilized an IWT resource as could be expected. Upgrades in the infrastructure are required for initialization of modal shift projects. This important fact is often forgotten, and proven intermodal solutions which “work on the pattern river” - Rhine - are sometimes suggested for the Danube. Table 4.1 provides an overview of the characteristics of the two rivers.

The Ro-Ro service on the Danube is not required to be examined here; for further information see the MUTAND and CREATING studies. It should be noted, however, that Ro-Ro service has several advantages taking into account that the largest trade in the Danube corridor is conducted by road vehicles. Thus, while the market share in the EU15 allocated to the road transport is around 70-75% (with unacceptable ~30% increase during the last ten years), in the SEEC it is currently above 90%; and increasing in the short term. The railway infrastructure in Austria is also regarded to be overcrowded. Consequently, seems that IWT, and particularly the Danube IWT, is the only alternative mode with enormous transport potentials, see Appendix 6.

Table 4.1 An overview of the Rhine and the Danube

The Rhine	The Danube
• Regulated river (ensured through many investments), guaranteed depths, often 3.5 m • Developed hinterland and transport infrastructure • 850 km navigable • Developed logistics • General knowledge about IWT potential does exist • Awareness about EST exist • Inland ports traffic: Rotterdam - 110 mill. t, Duisburg - 50 mill. t • 84% & 34% of European selfpropeled and pushed barges fleet, respectively • 56% tkm of EU15 IWT (IWT of EU27-EU15 accounts to only 5% tkm of EU27)	• Partially regulated river, shallow water on many sectors, occasionally 2.5 m • Undeveloped hinterland and transport infrastructure • Long river, 2400 km navigable • Undeveloped logistics concepts • Sufficient knowledge about potential of IWT does not exist • Awareness about EST does not exist • Inland ports traffic: Constanta – 35 mill. t Regensburg - 2.5 mill. t • 4% & 44% of European selfpropelled and pushed barges fleet, respectively

4.4. Concluding remarks

There is a dramatic difference between sea and IWT:

a) Sea vessels have no competition (without them international trade is impossible)
b) IWT has very strong competition from alternatives (railway and road transport)
c) IWT is more constrained by natural physical conditions as rivers flow through the mainland.

Consequently, the land transport modes “dictate” the cost of transport, but also the type of intermodal loading units that should be used. So, if standard ISO containers (TEU, FEU) work well on the sea, that does not yet mean they will be so competitive in IWT, i.e. IWT should adapt itself to other modes and hence standards that are broadly used in Europe, and in particular to pallet-wise domestic containers (EILUs) which are just 6-16 cm wider than the usual sea containers. Nevertheless, this small difference of only few centimetres poses problems in IWT, resulting often in un-competitiveness compared to land transport modes.

Efficient cargo handling (transhipment), not only in the ports/hubs but in the hinterland, is essential for successful intermodal transport. In other words, development of the hinterland, transport infrastructure, knowledge about IWT possibilities, EST, logistics etc. are decisive factors for application of intermodality. These explain why containerization is accepted on the Rhine, while the Ro-Ro technology seems to work better on the Danube.

IWT of containers is inherently a more efficient intermodal solution (than Ro-Ro) due to their stackability and stowability. Nevertheless, given that the Danube is not fully regulated and that it has shallows on several sectors, container vessels with lower carrying capacity (than on the Rhine, for instance) should be considered as a feasible solution. Barge trains with partly loaded barges would give good results too. In any case, a sufficient number of containers is necessary for successful IWT, and that depends very much on the development of the regional economy along the Danube corridor.

5. WATERBORNE TRANSPORT [SPIN, 26th Duisburg Colloquium]

The core of this report is given in the Section 8 where two typical designs - concept ships - will be developed. Concepts are usually based on previous research and successful vessels. Consequently, it was decided that a Section on state-of-the-art should be added.

5.1. State of the art

5.1.1. Selfpropelled vessel

Probably the most successful selfpropelled **general cargo and container** vessels on the Danube are of the class MGSS "Jochenstein" (Figure 5.1). These ships were built in the Osterreichische Schiffswerften AG in Linz-Korneuberg more than 20 years ago for German (about 10 vessels) and Soviet - now Ukrainian - shipping companies (about 15 vessels).

The MGSS "Jochenstein" was a prototype for (probably the only) recently-built selfpropelled vessel on the Danube (built for the JRB shipping company). 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).

Loa = 95 m
Boa = 11.4 m (some 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.

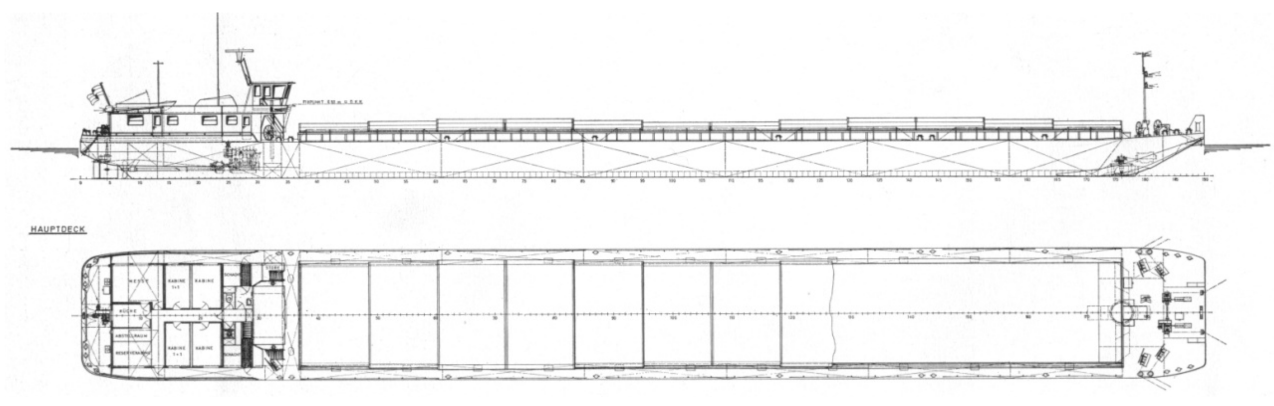


Figure 5.1 General Arrangement of MGSS "Jochenstein"

On the Rhine River (see Figures 5.2 to 5.4) much larger container ships exist, for instance the motor ship of the "JOWI" class that were followed by the recently-built "Zembla" (L=135.0 m, B=17.4 m, 500 TEU, 3200 kW). The Crane Barge "Mercurius Amsterdam" (86x11.5 m, 144 TEU, crane lift capacity 35t/30m, transhipment ~18 TEU/h) is suitable for short haul container transport and transhipment directly onto the quay (no need for port or hub) should also be mentioned as is the first river container ship equipped with its own transhipment equipment (Figure 5.5).

Figure 5.2 "Zembla" – one of the largest container ships on the Rhine (Source: INE)

Figure 5.3 Coupling train on the Rhine with a typical container ship of 4x4x13=208 TEUs

Figure 5.4 Small container vessel "Amer Hopper" - 86 x 7.03 x 2.86 m (Source: Mercurius)

Figure 5.5 Crane barge "Mercurius Amsterdam" (Source: Mercurius)

Concerning **selfpropelled bulk carriers**, the vessel "Sava Mala" (96.6 x 13.8 x 4.4 m) is amongst the largest on the Danube. Her capacity is 2600 t of bulk cargo; she has unique equipment that enables self-discharge to the shore or the hold of another vessel (these vessels are mainly used for gravel and sand transport). To increase capacity, high tensile steel was used for coamings and gangways, so the vessels are relatively elastic with unusually large sagging of around 25 cm.

The cement carrier "Sajkas" (102 x 11.6 x 3.5 m) has a capacity of 1500 t. The 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 converted into ordinary bulk carrier. The reason for this was that adequate shore capacities for cement acceptance were never built! This emphasises the importance of the overall transport chain and not just of the waterborne part.

The special bulk cargo ship "Mercurial-Latistar" (86 x 11.4 x 3.5 m) has self loading and unloading equipment for transport of flour bulk (Figure 5.6). Transport of flour by this particular ship and route (in the Rhine corridor) reduces 10,000 trailer moves a year.

Tankers (crude oil, products, chemicals etc.) are also present on IWW. One typical Rhine tanker is the "Einstein" (Figure 5.7) of 86 x 11.4 x 3.2 m, with 6 tanks totalling 2055t/2093m^3, with a power installed of 1080 kW. A large number of selfpropelled tankers and tank barges was decommissioned on the Danube when the oil pipeline was built (this was actually the first reason for decline of IWT on the Danube in recent history; the second was the war and UN sanctions in ex-Yugoslavia over the last decade).

Figure 5.6 Flour carrier "Mercurial-Latistar" (Source: Mercurius)

Figure 5.7 Typical selfpropelled tanker from the Rhine - "Einstein" (Source: Mercurius)

The recently-built **"Futura Carrier"** (and her three sister ships, Figure 5.8) has innovative semi-catamaran hull form with two propulsive devices at the bow (for minimum wave making), air lubrication (for reduced frictional resistance) applied for the first time to European inland waterway vessels (see Project SMOOTH, Section 5.2.4.), modular design concept (see Figures 5.21 and 5.23) etc. Hull form is optimised for shallow water and offers good manoeuvrability (with four identical azimuthing units). German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety co-funded the project. However, although the "Futura Carrier" is a very interesting concept, she is actually a river-sea vessel and as such cannot compete with river vessels (as some design compromises had to be made for sea sailing). Consequently, several innovations that were employed are not as attractive for the river vessels as they seem at the first sight.

Figure 5.8 “Futura Carrier” (Source: www.new-logistics.com)

5.1.2. Barge Trains

Pushboat technology was introduced on the Danube in 1961 (on the Rhine 1955) and was copied from the Mississippi River. There are two barge train types: a) a push train (push-boat + barges) and, b) a coupling train (motor ship + barge). Possible vessel formations on the Danube are depicted in Figure 5.9.

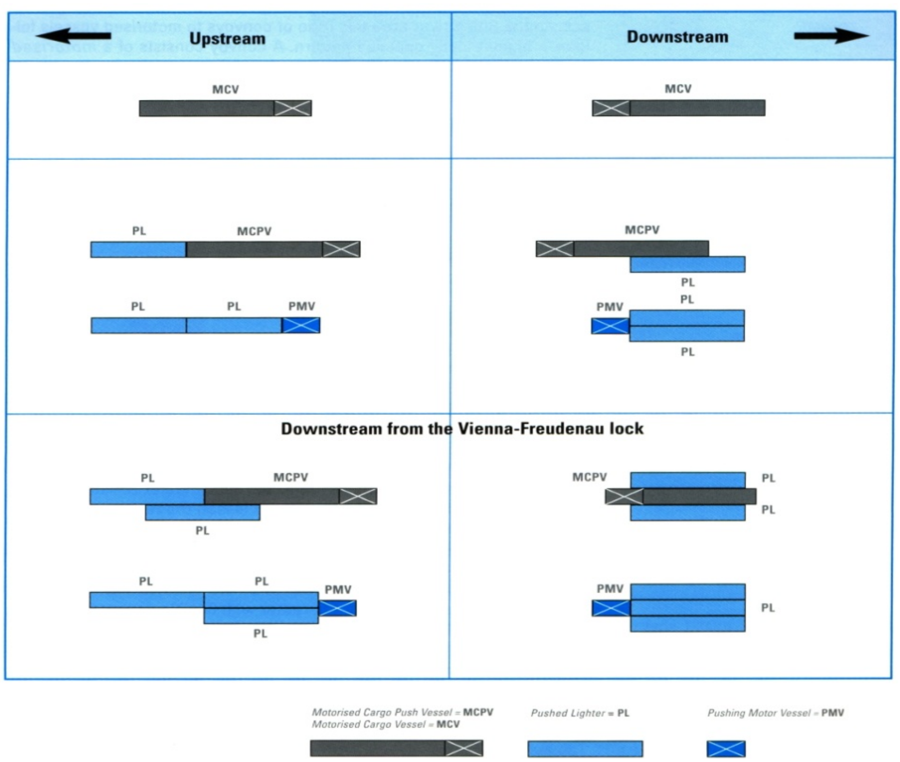


Figure 5.9 Possible vessel formations (Source: Manual on Danube Navigation)

The first pushboats were “Kablar” (Figure 5.10) and “Kosmaj” (owned by JRB). Soon after that, the pushboat technology was introduced in other Danube corridor countries; today pushboats dominate the Danube waterway. Relatively large barge convoys were pushed (when oil was transported, before the pipeline was built), 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, see Figure 5.11 to 5.13.

Figure 5.10 The first newly-built pushboat on the Danube - “Kablar”; it is still in operation

Figure 5.11 One of the largest convoys on the Danube (with tank barges) (Source: Grubor)

The main advantage of pushing vs. towing is that less power is needed for pushing, which may be explained through use of so-called *train formation coefficient* - c_T. Namely, $c_T=R_T/\Sigma R_i$, where R_T is total resistance of barge train and R_i is individual resistance of each barge in a pushed formation. So, c_T is always less than one and is between 0.65 and 0.85 (lower values are for slender barge train configurations) and is around 0.75 for a typical coupling train. c_T for towing configurations is a bit higher, or in other words, with the same power pushing speed is up to 10% higher than the towing speed. Moreover, steering of towed barges was often necessary, requiring extra manpower onboard.

Nevertheless, although somewhat obsolete, the towing technology was never quite abandoned on the Danube. Towing technology has some advantages, particularly during dry seasons when the water level is low, as towing tugs have much smaller draught than contemporary pushboats. Furthermore, the towing technology may be applicable on the sea, whereas pushing is not possible due to wave size.

Figure 5.12 Pushing train consisting of 6 Europe II barges - about 190x34.2 m, up to 16,000 tdw depending on the draught (Source: CREATING WP5)

Figure 5.13 Pushing train consisting of 9 Europe II barges (about 260 x 34.2 m)

Possible formations along the Danube corridor are depicted in Figure 5.9, while Table 5.1. shows ECE classification of European inland waterways.

Table 5.1 ECE classification of European inland waterways, vessels and pushed convoys (Source: Manual on Danube Navigation)

Inland Waterway Type		Inland Waterway Class	MOTOR VESSELS AND LIGHTERS Type of vessel: general characteristics					PUSHED CONVOYS Type of convoy: general characteristics					Minimum height under bridges (m) [2]
			Designation	max.Length L(m)	max.Beam B(m)	Draught d(m) [7]	Tonnage T(t)	Formation	Length L(m)	Beam B(m) [7]	Draught d(m) [7]	Tonnage T(t)	
1		2	3	4	5	6	7	8	9	10	11	12	13
of regional importance	West of Elbe	I	Penische	38.5	5.05	1.8 - 2.2	250 - 400						4.0
		II	Kempenaar	50 - 55	6.6	2.5	400 - 650						4.0 - 5.0
		III	Gustav Koenigs	67 - 80	8.2	2.5	650 - 1,000						4.0 - 5.0
	East of Elbe	I	Gross Finow	41	4.7	1.4	180						3.0
		II	BM-500	57	7.5 - 9.0	1.6	500 - 630						3.0
		III	[6]	67 - 70	8.2 - 9.0	1.6 - 2.0	470 - 700		118 - 132 [1]	8.2 - 9.0 [1]	1.6 - 2.0	1,000 - 1,200	4.0
of international importance		IV	Johann Welker	80 - 85	9.5	2.50	1,000 - 1,500		85	9.50 [5]	2.50 - 2.80	1,250 - 1,450	5.25 or 7.00 [4]
		Va	Large Rhine vessels	95 - 110	11.40	2.50 - 2.80	1,500 - 3,000		95 - 110 [1]	11.40	2.50 - 4.50	1,600 - 3,000	5.25 or 7.00 or 9.10 [4]
		Vb							172 - 185 [1]	11.40	2.50 - 4.50	3,200 - 6,000	
		VIa							95 - 110 [1]	22.80	2.50 - 4.50	3,200 - 6,000	7.00 or 9.10 [4]
		VIb	[3]	140	15.00	3.90			185 - 195 [1]	22.80	2.50 - 4.50	6,400 - 12,000	7.00 or 9.10 [4]
		VIc							270 - 280 [1]	22.80	2.50 - 4.50	9,800-18,000	9.10
									195 - 200 [1]	33.00 - 34.20 [1]	2.50 - 4.50	9,600-18,000	9.10 [4]
		VII						[8]	285	33.00 - 34.20	2.50 - 4.50	14,500-27,000	9.10 [4]

[1] The first number reflects the current situation, while the second takes future developments as well as – in some cases – the current situation into account.

[2] Refers to the safety clearance of approximately 30 cm between the highest fixed point of the vessel or its cargo and a bridge.

[3] Refers to the dimensions of self-propelled vessels that are expected in roll-on/roll-off and container transports. The given dimensions are approximate values.

[4] Designed for transporting containers:
5.25 m for vessels carrying two layers of containers,
7.00 m for vessels carrying three layers of containers,
9.10 m for vessels carrying four layers of containers,
50% of the containers can be empty, otherwise *ballasting* is necessary.

[5] Based on the longest permissible length of vessels and convoys, some waterways can be classified as class IV, although their greatest width comes to 11.40 m and their greatest draught to 4.00 m.

[6] Vessels that are used in the Oder region and on the waterways between the Oder and the Elbe.

[7] The draught for certain inland waterways is to be set in accordance with local provisions.

[8] On some sections of class VII waterways, pushed convoys with a larger number of lighters can be used. In this case, the horizontal dimension may exceed those values listed in the table.

5.1.3. <u>Barges</u>

By far the largest majority of Danube barges have breath of 11 m, while some are made according to the Rhine standards and have breadth of 11.4 m (see Sections 4.2 and 2.4 - Implications on ship design). In addition, many barges are 9.5 m wide, not to mention old towing vessels occasionally used in pushed trains. Usually, but not necessarily, Danube barges have draught of up to 2.5 m and height of 2.7 m, while barges for the Rhine are deeper (draught of up to 3.95 m and height (depth) of up to 4 m), see Table 5.2.

Table 5.2 Most common river barges (Source: CREATING WP5)

Barge type	Dimensions (L x B)	Tonnage capacity at a draught of				Area of use
		2,00 m	2,50 m	2,80 m	4,00 m	River or corridor
Europe Type I	70,00 m x 9,50 m	940 t	1240 t	-	-	Rhine, MLK
Europe Type II	76,50 m x 11,40 m	1250 t	1660 t	1850 t	-	Rhine, MLK, Danube
Europe Type IIa/b	76,50 m x 11,40 m	1140 t	1530 t	1800 t	2800 t	Rhine
Danube-Europe Type II	76,50 m x 11,00 m	1100 t	1500 t			Danube

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 characteristics are B=11 m, H=3.9 m, T=3.3 m, corresponding to dwt=1070 t with a lightship weight of 240 t). Nevertheless, there are several other barge types along the Danube corridor, e.g. see Figure 5.14.

Figure 5.14 SB barges with a capacity of 80 TEU used for the container transport on the route Belgrade-Constanta. Presently, this is the only available container service on the Danube (Source: Nord Marine)

5.1.4. Pushboats

Long range and harbour pushboats were built on the Danube and most of them had two propellers, but large pushboats with three propellers were not rare. Besides the draught restriction, Danube pushboats generally differ from those on the Rhine as they have more accommodation space; Danube pushboats have larger crews that work in shifts, as the Danube is a much longer river than the Rhine, i.e. more time is spent sailing.

During the 1970s, after some experience was gained, a kind of standard or recommendation emerged in Eastern Bloc shipping companies concerning long-range Danube pushboats. Besides the standardised mooring equipment, ships have around 2 x 1200 HP (2 x 880 kW), a length of around 35 m, a breadth of 11 m (like Danube barges) and draught of less than 1.9 m. These pushboats were built in series in all Danube countries downstream of Austria.

Worth mentioning are also the largest pushboats on the Danube – “Karadjordje” and “Karlovac” – built in the shipyard “Tito” (now “Belgrade”) for JRB (see Figure 5.15). One of the pushboats was equipped with a special system (device) for rudder unloading. The reason for this innovation was that (floating) logs were often wedged in the nozzles and/or main or flanking rudders, which sometimes blocked or damaged the rudders. So, the purpose of the rudder unloading device was to permit the rest of the rudders (those which were not blocked by logs) to execute their function. Although the purpose of this invention sounds logical, due to the poorly-developed mechanism (prototype) and the need for frequent interventions, the unloading device was soon replaced with the usual system of connecting rods. Another recent reconstruction was made to enable only two propellers/engines to be operational (the middle shaftline was removed).

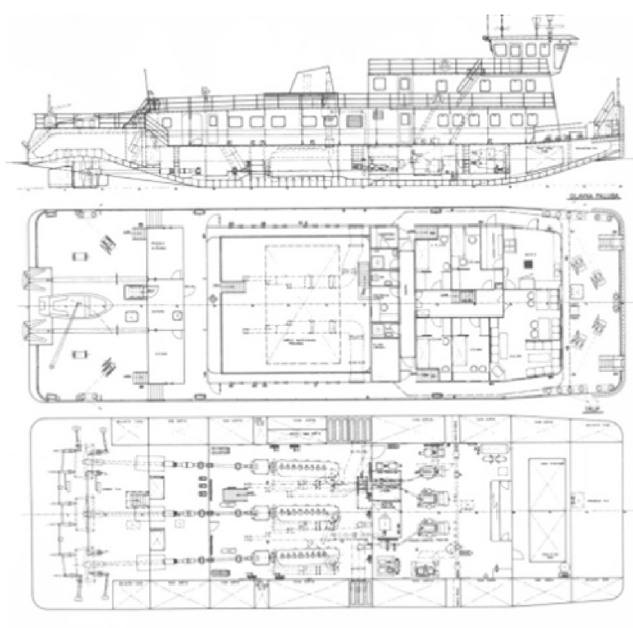


Figure 5.15 General arrangement plan of “Karadjordje”, the largest pushboats on the Danube

Loa=40.45 m, B=13.0 m, H=2.8 m,

T=1.95–2.15 m, P_B= 3 x 1294 kW,

V=14 km/h with 12 barges 1700 tdw each

Although not a pushboat, due to its unique electric propulsion, an Austrian river icebreaker "Roethelstein" with Azipod propulsors should be mentioned (see Figure 5.16). During trials, the "Roethelstein" proved its 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 a cylindrical bow, parallel mid body and an underflow stern feeding water to the poded azimuth propulsion units. "Roethelstein" is an interesting vessel because of its propulsion system, i.e. the application of the Azipod principle with low power demands.

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

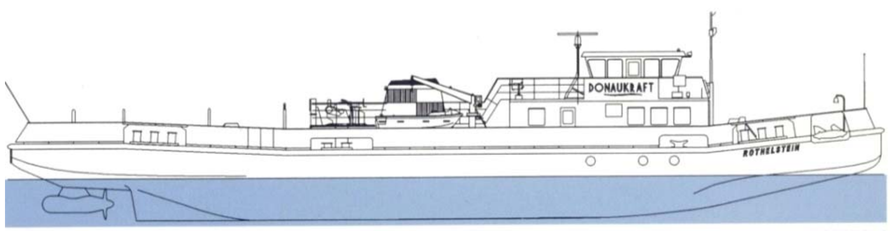


Figure 5.16 River ice breaker "Roethelstein" (Source: Ship & Boat Int.)

Pushboats from other European rivers might also be of interest for this study, for instance those of "Elbe" class (Figure 5.17) – their draught is only 0.85 m! Other characteristics are L=28.6 m, B=10.3 m, highest fixed point 4.25 m, W=166 t, P=2x220 kW.

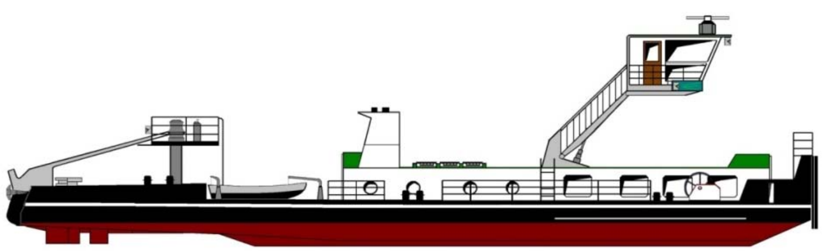


Figure 5.17 Pushboat of "Elbe" class (Source: Deutschen Binnenreederei Holding AG)

5.2. Concepts of researched inland vessels for cargo transport

Several research and development projects have been carried out on inland vessels. Most of these projects were based on contemporary technology and only some particular aspects were researched. For instance, in the CREATING project the main investigation was directed towards environmental aspects that would still be economically acceptable for shipowners. In the INBISHIP project, electric propulsion was specially investigated. In the INBAT and VEBIS projects, extremely shallow water vessels were investigated, and in the MUTAND project just Ro-Ro service for the Danube was treated. Some of the projects are important for this study and will be mentioned here.

5.2.1. Selfpropelled vessel INBISHIP

INBISHIP (Common European Inland Vessel Concept) is an innovative approach to inland ship design powered by a diesel-electric system with a pod propulsion system, optimum hull lines in terms of resistance, excellent manoeuvrability and increased economical efficiency in inland shipping operations (see Figures 5.18, 7.12 and 7.13). Amongst the novelties is that the engine room can be placed anywhere in the ship (even at the bow if necessary) as there is no direct coupling of engines and propellers. As a consequence the machinery requires less space due to the adopted diesel-electric power system, hence cargo space may be increased (in particular, on a 110 x 11.4 m ship one container layer more can be loaded!). This type of ship design leads to lower fuel consumption, emission levels and maintenance costs.

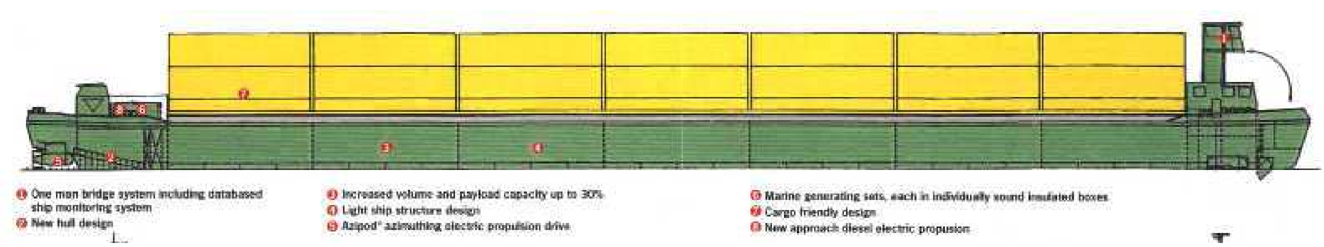


Figure 5.18 INBISHIP concept

5.2.2. Pushboats and barges for extremely shallow water – VEBIS and INBAT projects

Over longer periods, the Elbe and Odra Rivers allow ship draughts of 1.0-1.4 m only. With the reunification of Germany, the R&D project VEBIS (acronym for improvement of the efficiency of inland water transportation) was initiated. The goal was twofold: a) to increase transport capacity on existing waterways, and b) to enable effective operation at larger draughts. So, amongst others, pushboats with a draught between 0.8 and 1.7 m with pump-jets and propellers were developed (lines of shallow draught pushboats and of selfpropelled vessels are shown in Figures 5.19 and 7.3, respectively).

An EU project under the acronym INBAT (INnovative BArge Train) was initiated after the VEBIS project with a similar goal, i.e. development of barge train that will operate efficiently at draughts ranging from 0.6 to 1.7 m (see Figure 5.20). Within INBAT, amongst others, application of new light weight construction materials and structural designs were investigated (see Figure 7.7). Modular pushboat designs (Figure 5.21) and new propulsion concepts were also investigated.

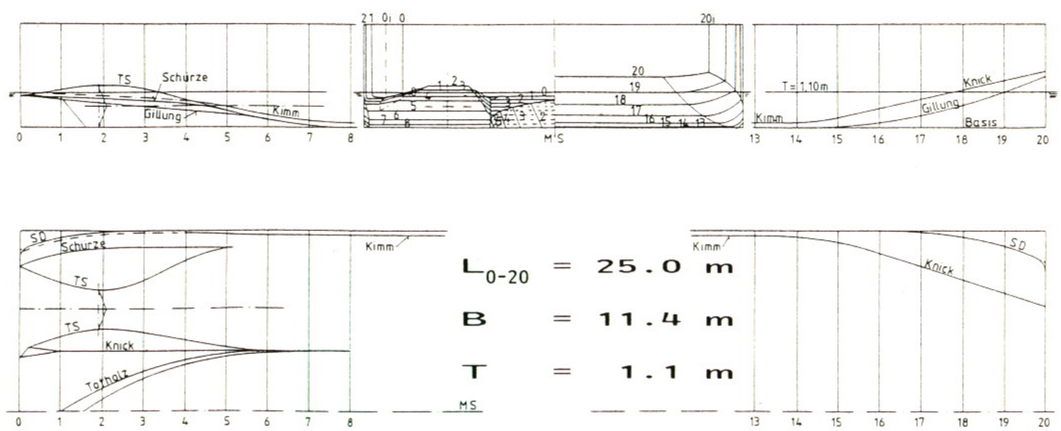


Figure 5.19 VEBIS Pushboat with a propeller of 1.2 m in nozzle

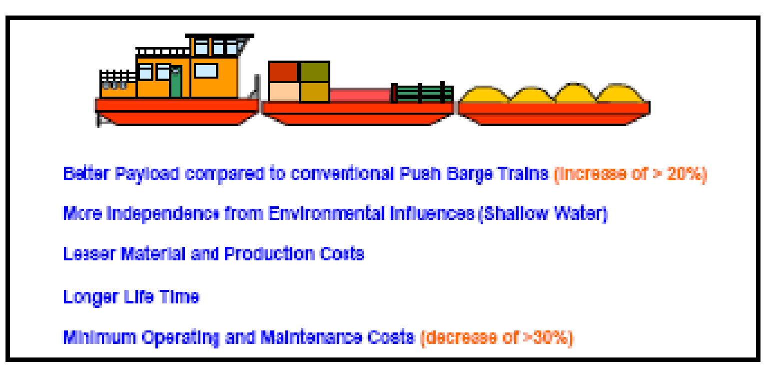


Figure 5.20 INBAT Targets (Source: Guisnet et al. 2004)

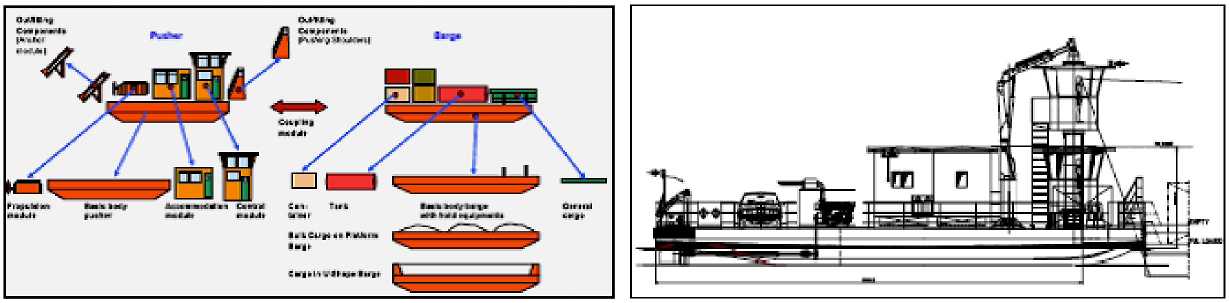


Figure 5.21 Pushboat modules (Source: Guisnet et al. 2004)

The shallow draught pushboat developed for the INBAT project has a retractable middle rudder-propeller (in order to enhance manoeuvrability and to reduce resistance when not in use) together with two classical horizontally driven shaft propellers (Figure 5.22). During operation in very shallow water, only side propellers are supposed to be used (the central propeller is retracted), while in deeper waters the central propeller would be used too to increase the barge train speed.

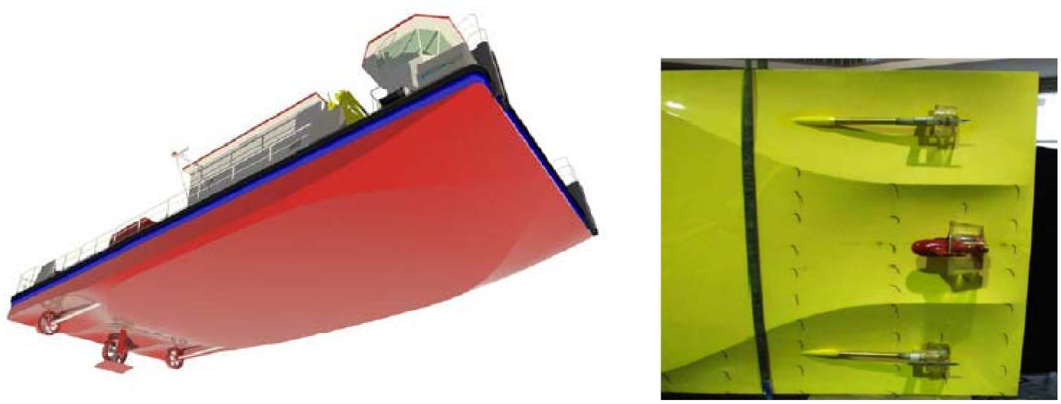


Figure 5.22 The Pushboat propulsion arrangement developed within INBAT project (Guesnet et al. 2004)

5.2.3. <u>Some other projects similar to the INBAT and INBISHIP projects</u>

A modular vessel was built in Serbia/Yugoslavia, see Figure 5.23; this vessel was named MMPO (Modular Multi-Purpose Vessel - 13.75 x 7.6 x 2.4 m) and consisted of a propulsive module with a driving complex, connecting modules (pallets) which provide stiffness, accommodation modules and a wheelhouse module.

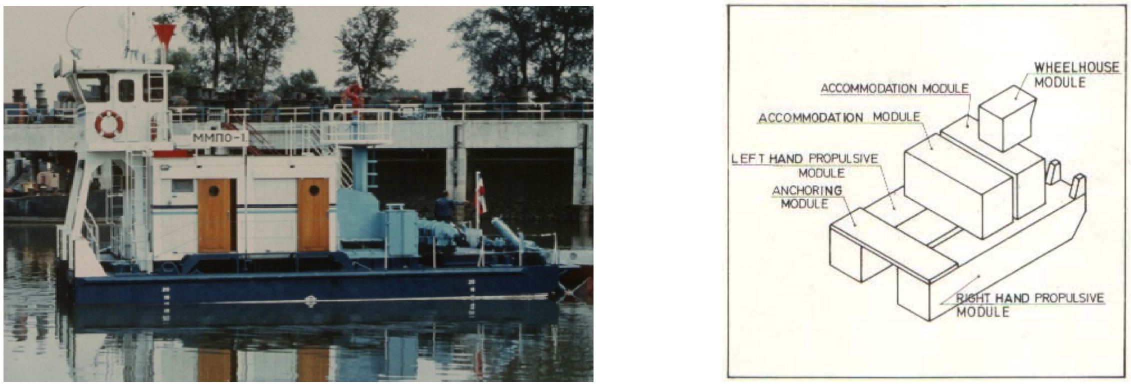


Figure 5.23 Modular Multi-Purpose Vessel – MMPO (Source: Shipyard "Belgrade")

Similar to the INBAT propulsion concept, the so called "hybrid pushboat" (Bilen and Zerjal 1998), has one large central propeller of 1.85 m with a conventional shaftline and two azimuthing and retractable hydrostatic side propellers of 1.35 m. The proposed hybrid pushboat has two diesel engines in line, see Figure 5.24. The first one is connected to the central, mechanically-driven propeller, while the second engine drives two hydrostatic side propulsors via hydraulic transmission system (thus enabling independent and flexible control). So, load distribution between central and side propellers is optimised. The main advantage of this arrangement is the possibility to draw nominal power for a particular convoy also enabling good manoeuvring characteristics. This is similar to the INBISHIP propulsion concept, as the hydraulic transmission is equivalent to electric transmission (however, the second has higher efficiency).

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

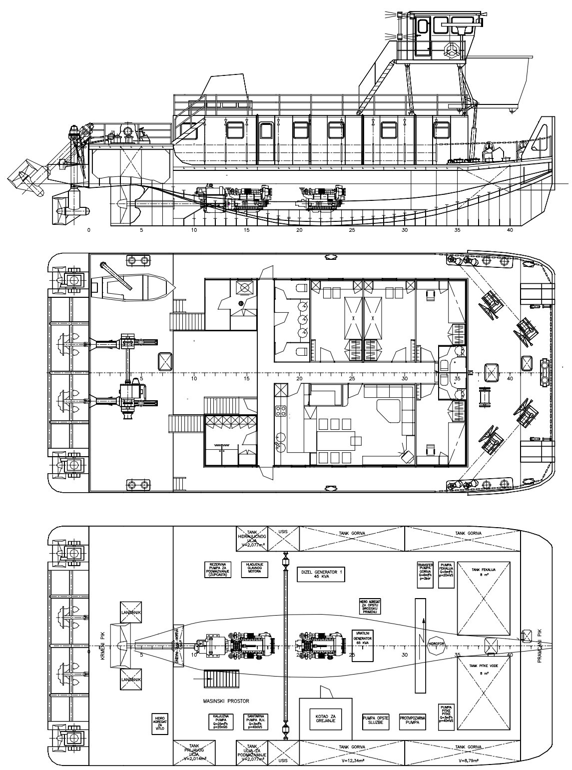


Figure 5.24 Hybrid pushboat - project (Source: Bilen and Zerjal 1998)

5.2.4. Concepts of advanced vessels

Nevertheless, some researched projects carried out concern advanced vessels whose time, seems, did not come yet due to various reasons. Beside necessary costs for the development of a new concept, one of the reasons is that innovations are not so easily accepted by the traditionally conservative inland shipping society, which accepts proven, durable and safe products. In that respect, note that the average age of the Rhine and Danube vessels is around 50 and 30 years, respectively (see Appendix 6).

Some of the concepts of researched advanced vessels that "never came to be" are:

- PASCAT (Partial Air cushion Supported CATamaran) – a catamaran vessel with hovercraft/SES capabilities that has advantages at relatively higher speeds, but still requires very large power to be installed compared to contemporary ships – Figure 5.25.
- PELS (Project Energy-saving Air-lubricated Ships) followed by SMOOTH project (Sustainable Methods for Optimal design and Operation of ships with air lubricaTed Hulls) – the aim was to reduce frictional resistance of flat-bottomed vessels (like river vessels) for around 20% by pumping air under the bottom. Recent full-scale trials on 83 m air cavity system (ACS) seagoing ship *ACS Demonstrator,* which was 1:4 scale model of a very large crude oil carrier, revealed fuel savings (hence CO_2 too) of up to 15% – Figure 5.26.
- A ship with movable buoyancy bodies (width increases from 9 m to 12.6 m) suited particularly to operate on shallow water; bodies move by hydraulic cylinders enabling draught reduction without reducing the cargo quantity – Figure 5.27.

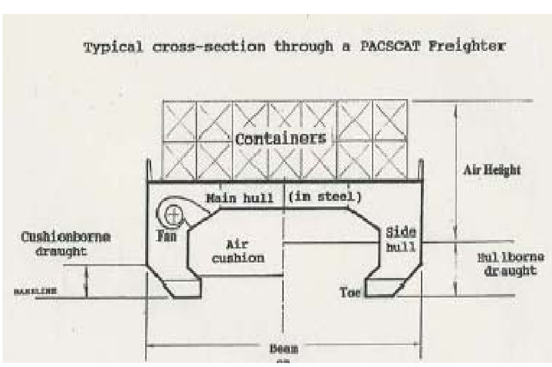


Figure 5.25 PASCAT concept

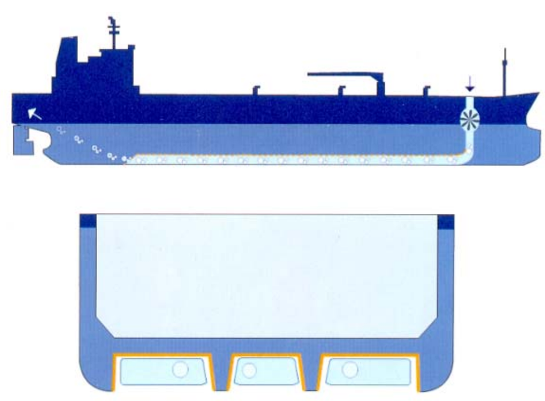


Figure 5.26 The principle of air cavity system (Source: The Naval Architect)

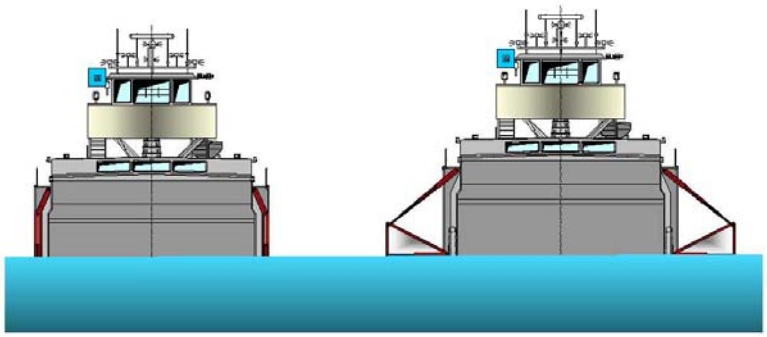


Figure 5.27 Cross section of inland ship especially suitable to operate on shallow water (Source: SPIN Rhine)

5.3. Concluding remarks

Existing types of ships and available new technologies were reviewed to help create a design for a shallow draught Danube ship (see Section 8).

Partly loaded barges can be the simplest and cheapest answer to restricted draught problems, taking into account that power needed to push an additional barge (or few of them) rises slightly, while cargo volume can increase rapidly. If this is the case, the problem usually poses the draught of a pushboat which cannot be reduced. So, a shallow draught pushboat would be advantageous in these situations.

On the other hand, selfpropelled vessels are faster and therefore more suitable for container transport (which has to compete with land transport modes, i.e. railway and truck).

Barges are by far the best for transport of large quantities of relatively cheap cargo, like bulk cargo (coal, ore, gravel, sand, grain etc.). For liquid cargo (oil and petroleum products) both ship types - barge trains and selfpropelled vessels - are used.

Concerning researched inland vessels, of particular interest for this study are the INBISHIP, VEBIS and INBAT projects. Some interesting aspects of these projects will be mentioned in the following sections.

The main reason why the innovative ship types are not applied on a broader scale is economics. Namely, as already mentioned, reduced loading (resulting in lower draught navigation) seems to be the cheapest solution to adapt to dry seasons and shallow water. Consequently, state subsidies should probably be considered as necessary to give new designs any chance to enter the market.

6. CHARACTERISTICS OF SELFPROPELLED CONTAINER VESSELS ADAPTED TO THE DANUBE WATERWAY [COVEDA, SPIN]

The problems connected to the design, construction, hydrodynamics, stability, etc. of inland container vessels 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, and 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 a 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.

6.1. Maximal vessel dimensions

As expected, the number of transported containers (which influences transport efficiency) depends on vessel length, beam and draught. A reasonable number of carried containers on IWW can vary from three to six abreast. So, proper beam of Danube 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
$B \approx 16.5$ m, for 6 containers abreast

In the case of four containers abreast, the beam should not exceed 11.4 m (max. 11.45 m) so the vessel can pass through the 12 m locks on the Upper Danube. Consequently, 11.4 m became a de-facto standard, although this breadth is less significant for the Middle and Lower Danube, where vessel beam is practically unlimited by the locks.

The relationship between number of TEU containers and vessel main dimensions is depicted in Figure 6.1. With these diagrams, the choice of vessel length and beam 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 different L/B ratios. This decision depends on numerous stability, resistance, propulsion and strength considerations.

The average mass of containers changes randomly from trip to trip. However, the long-term, average value for a standard 20 foot container (TEU) can be assumed to be around 13 t. This mass is called the *required container mass.* Nevertheless, average *available container mass* (m_c)

for inland vessels is limited and is in direct correlation to its restricted draught T and number of container layers (n_H), while the other parameters are of secondary importance. Only a certain combination of T and n_H imply a well-balanced vessel having, for instance, $m_c \approx 13$ t. Consequently, design of a well balanced inland shallow draught container vessel is not easy.

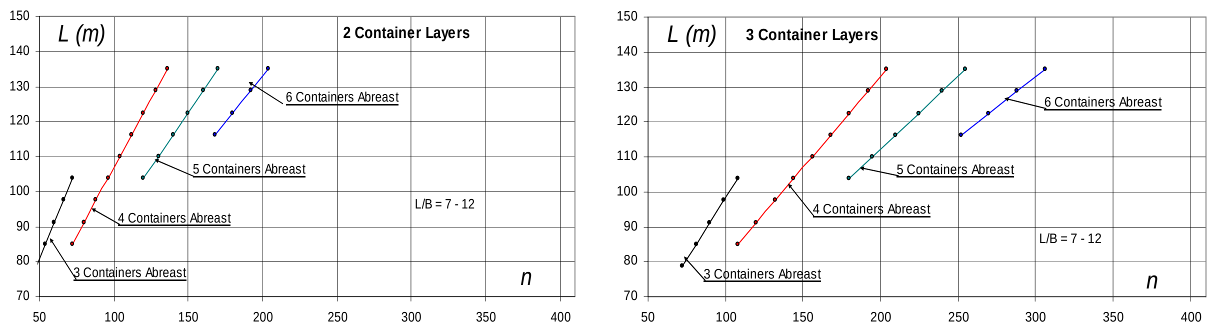


Figure 6.1 Relation of vessel length to number of TEU containers

One method of increasing the available container mass - without decreasing the number of containers or increasing draught – is to reduce the lightship weight. This is usually too expensive (as new technologies and new materials should be applied). It is also possible to increase the vessel breadth, without increasing the number of containers abreast. For example, for four containers abreast, vessel beam could be 12-13 m, rather than 11.4 m.

The draughts that would give the required container mass of 13 t are presented in Figure 6.2. So, draught should be between 3 – 3.25 m for the four-layer vessels usual on the Rhine. Three-layer vessels with draughts (T) between 2.25 – 2.5 m and two-layer vessels with T = 1.6 – 1.85 m are acceptable for the Danube. Nevertheless, the choice of draught is influenced not only by the statistics of waterway depth, but also by available cargo and other transportation, financial reasons, technical characteristics of the vessel, etc.

Air draught might also be critical, since minimal air clearance (above high water level when passing bellow bridges) is 5.25 m and 7.00 m for two and three container layers respectively (see Table 2.2 – bridge heights). Sometimes this could be overcome by ballasting the ship, but this increases transport costs.

Consequently, due to water and air draught restrictions, waterborne transport of containers on the Danube is less efficient than on the Rhine. On the Danube, a vessel of the same size can transport one to two container layers less than on the Rhine!

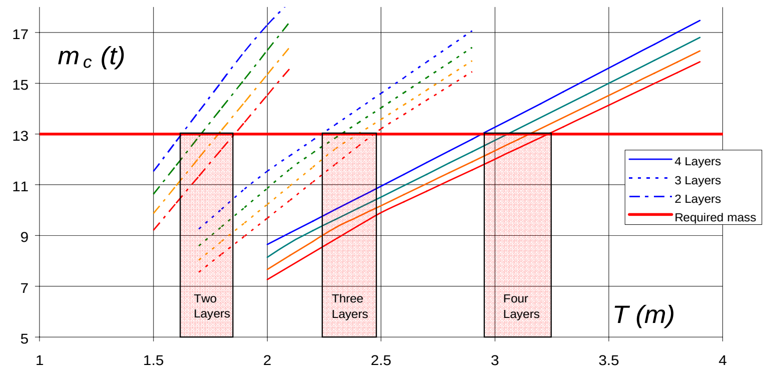


Figure 6.2 Draughts for two, three and four layer container vessels

6.2. Transport economy

Container vessels should have full form (due to draught restrictions), but the L/B ratio (long or beamy vessel) has yet to be clarified. In that respect, the transport economy from a hydrodynamic point of view, or the coefficient of container transport efficiency (C_C), was introduced. So,

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

shows that adding a container layer, or removing a row of containers abreast, dramatically increases efficiency. The large container vessels with 5 or 6 containers abreast never reach the efficiency of less beamy vessels. Also, smaller vessels, in this sense, are found to be advantageous.

The choice between a Long and Beamy vessel (overlapping of curves in Figure 6.1) is actually a choice between L/B=10-12 or L/B=7-9 (having the same draught). Longer vessels are advantageous from the wave-resistance point of view, while beamy vessels are better in stability (which is satisfied in all cases) and hull-weight considerations. Therefore, the compromise should be made between resistance and weight considerations.

Reduction in hull weight is significant for inland container vessels because of their limited draught. A rough analysis (for three container layers) indicates that the reduction of hull weight by choosing a beamy instead of a long vessel is approximately 10 - 15%. This allows an increase of available container mass of approximately 5 - 10%.

The wave resistance in shallow water depends mainly on parameters L/h and L/B, and both of these parameters decrease if a beamy vessel is chosen instead of the long one. The reduction of L/h would be beneficial if resistance is influenced by the waterway bed, which is the case for high, near-critical speeds only, i.e. high F_{Nh} (see Figures 3.2 to 3.4). However, usual speeds of the fastest selfpropelled vessels correspond to much lower F_{Nh} values, certainly below F_{Nh}=0.65. Consequently, resistance is influenced mainly by the change of the parameter L/B*.* Wave resistance significantly decreases by choosing a long instead of beamy vessel. For instance, by choosing the longer ship, the coefficient of container transport efficiency C_C could increase up to 20% (see Figure 6.3), which is large enough to compensate the opposing increase of hull weight. The trends on the Rhine seem to be in favour of this approach, as they show the tendency towards the vessels having L/B>11.

Concerning selfpropelled container vessels for Danube tributaries (e.g. Sava, Tisza), it follows from the previous discussion and Table 2.3, that smaller vessels of B ≈ 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, see Table 5.1) than according to Figure 6.1, the carrying capacity would be around 50 to 75 TEU containers, for two and three container layers respectively.

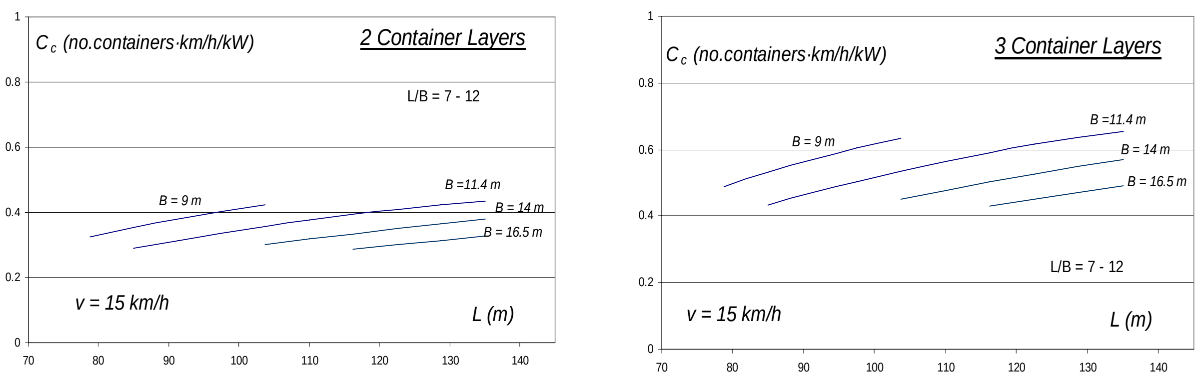


Figure 6.3 Coefficient of container transport efficiency C_C for different *L* and *B*.

6.3. Hydrodynamic analysis

All commercial river vessels, including container vessels sail at subcritical speeds (see Section 3) below the high resistance region, i.e. usually at the 'economic' speed (V_{ec}) which follows from F_{nh}≈0.65-0.70 (see Figure 6.4). So, for a river depth of 5 m, the economic speed would be around 16-17 km/h, while for depth of only 2 m it would be reduced to only 10-11 km/h. Within the subcritical region it can be shown (COVEDA study) that slower vessels have higher transport efficiency. Note, however that the cost of speed and the benefits of the increased number of voyages was not included in the above-mentioned C_c coefficient.

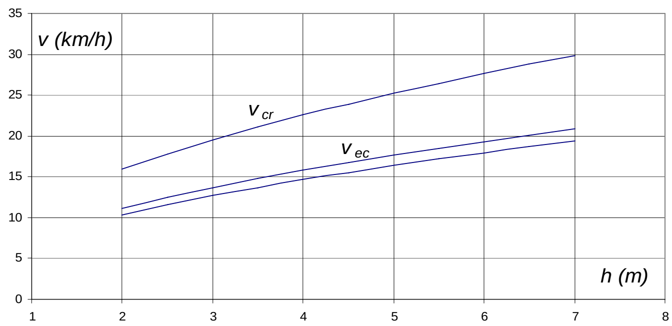


Figure 6.4 Economic and critical speeds

The influence of propeller diameter on transport efficiency (Figure 6.5) also gives an unexpected result. Although efficiency increases with the increase of propeller diameter, the influence is relatively small. Taking into account all the risks connected with large propeller diameters, it follows that somewhat smaller propellers could often be advantageous. This conclusion is considered in more detail by analysing the propulsive efficiency η_D. The results are presented in 3D and 2D diagrams below (Figures 6.6 and 6.7), also showing the minimal diameter due to the cavitation criteria. 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.

It should be noted that in contrast to the draught (which could be reduced by smaller cargo weight), once chosen, the propeller diameter cannot be changed. It follows, logically, that the propeller should be designed according to the minimal draught requirements. Such choice implies, however, a possible reduction of its efficiency.

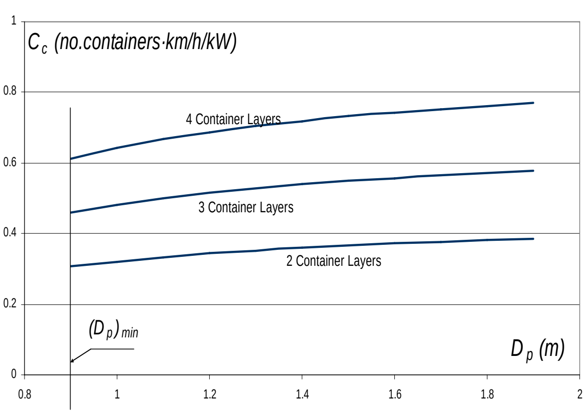


Figure 6.5 Coeff. of container transport efficiency for different propeller diameters

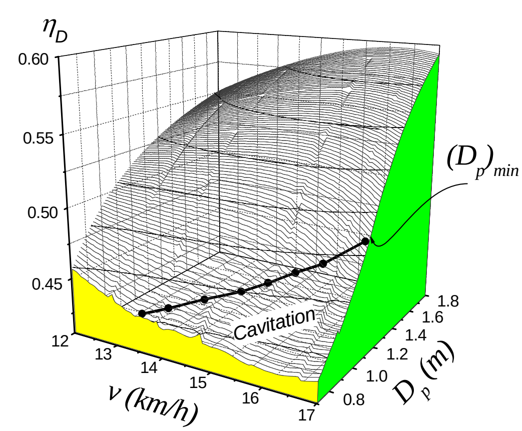


Figure 6.6 Propulsive efficiency as a function of speed and D_p

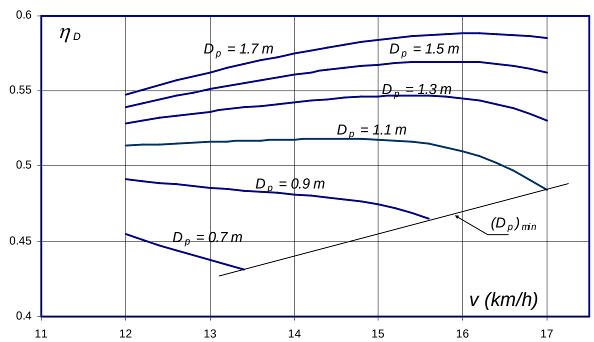


Figure 6.7 Propulsive efficiency η_D as a function of speed and propeller diameter

6.4. Hull weight considerations

It is essential to correctly assess the mass of lightship in very early stages of ship design, not only to obtain the right displacement, deadweight or draft, but also to analyse the available average container mass and verify if a limited draught vessel could be well-balanced. This can be assessed from the diagram shown in Figure 6.8 (Heuser 1986) which presents lightship mass for the steel only (without machinery and equipment) of Rhine commercial vessels as a function of vessel cubic module L·B·H. This data was enriched with few available results, presented by the dots in the diagram. Note that some other sources gave smaller weight than shown in Figure 6.8, although the curve's trend is the same.

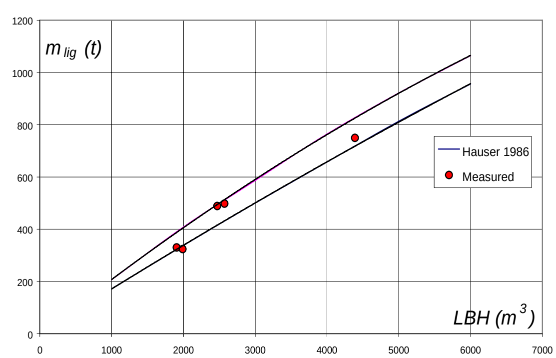


Figure 6.8 Lightship mass (steel only) of selfpropelled vessels (on abscissa given is a cubic module, i.e. L x B x H m^3)

6.5. Concluding remarks

Summarising, some unexpected results were obtained by analysing vessel characteristics, such as propeller diameter, propulsive efficiency, container transport efficiency etc. It is however, still discussable whether long and narrow vessels (that have smaller resistance) are advantageous over large, beamy ones (which are comparatively lighter and therefore cheaper). Conclusions regarding ship dimensions are based on the assumptions mentioned above; other parameters of transport efficiencies (e.g. transport costs) could give different answers (resulting, for instance, in vessels of the "Jowi" class, see Figure 5.2). A very important conclusion, however, is that profit in the first place depends on number of containers onboard, and that all other factors are by far less important.

The relatively insignificant influence of screw diameter on overall efficiency indicates the advantages of somewhat smaller propellers. Actually, this means that splitting the total power to more propellers, but of a smaller diameter, can enable navigation in shallow water. Nevertheless, this will definitely increase the investment (shipbuilding) costs.

On the Lower Danube attention should be paid to the restrictions of low water draught and high air draught (which is not the case on other Danube stretches), so one might come to a wrong idea to load larger than the allowed number of containers onboard.

In any case, conclusions derived in the COVEDA study, which are partly presented in this section, are useful. A rough algorithm for estimating the vessel's main dimensions is depicted in Figure 6.9.

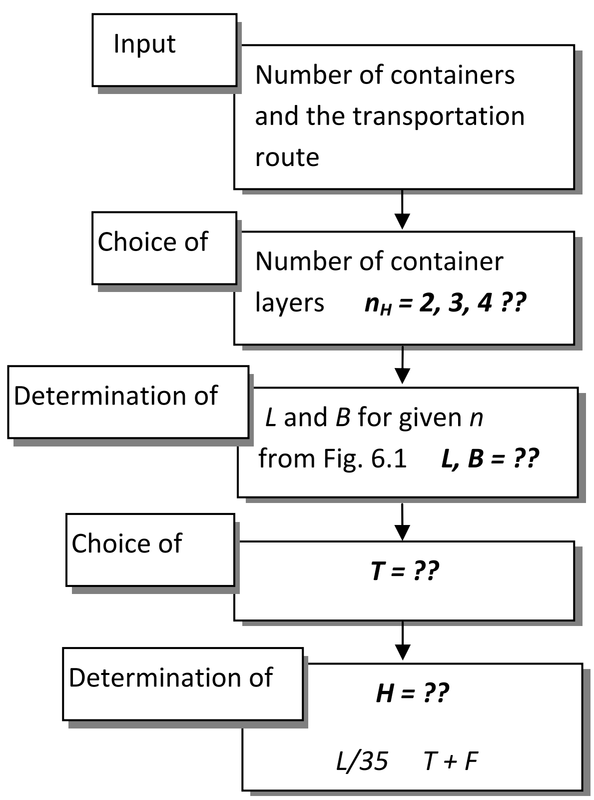


Figure 6.9 An algorithm for estimating vessel main dimensions

7. TECHNICAL MEASURES THAT MAKE INLAND SHIPS CLEANER AND MORE EFFICIENT [SPIN, Ro-Ro 2008, CREATING]

Generally speaking, environmentally sustainable and cheap IWT is possible if:

a) Contemporary logistic concepts are applied
b) Transhipment is efficient
c) Waterborne transport is efficient

Issue c) can be achieved by reduction of investment costs (application of *design for manufacture techniques,* for instance), reduction of maintenance costs, reduction of crew members (costs) and reduction of fuel costs. Note, however, that only few of the above-mentioned are actually technical issues!

The last issue – reduction of fuel costs – depends, amongst others, on the fuel efficiency of ship; this is purely a technical measure that will be discussed in this section according to the scheme shown in Figure 7.1 (the formulae given at the bottom was previously explained in Section 3). Namely, the main technical measures to enable building of a more efficient ship, hence cleaner and therefore more environmentally friendly, are divided into four main groups. Each group is further divided into sub-groups and will be discussed separately. Energy saving (fuel efficiency) of waterborne transportation is the main goal here, but attention should always be paid to safety, as well as to reduction of overall direct and indirect costs.

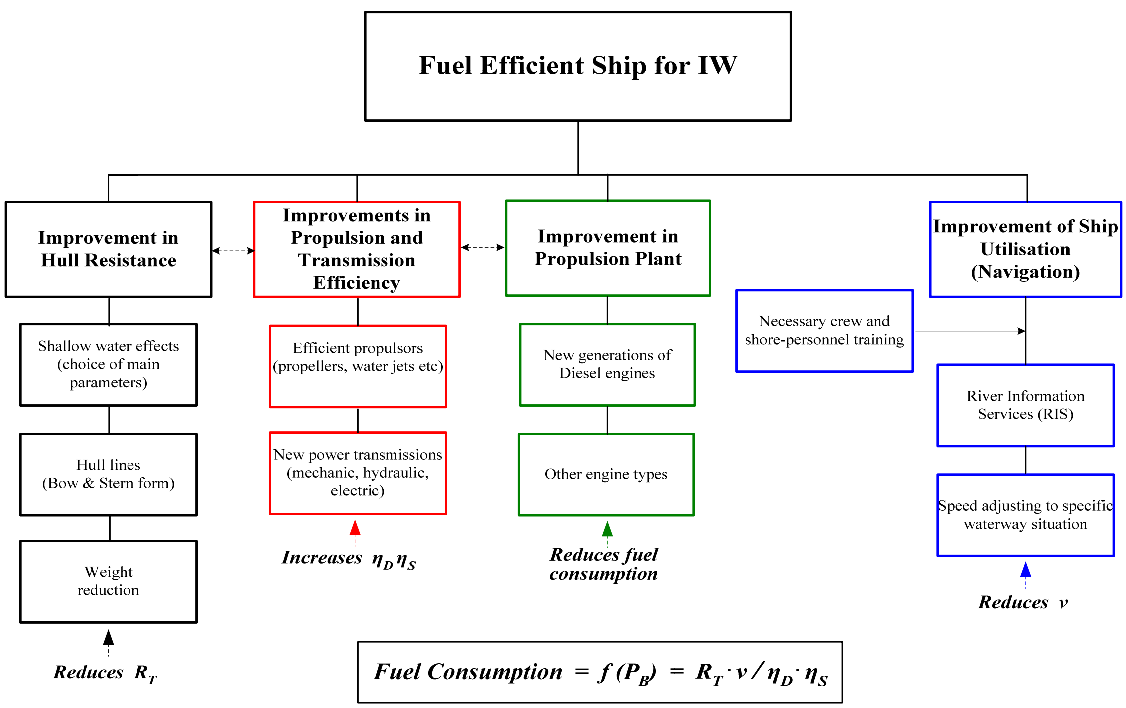


Figure 7.1 Measures that lead to fuel efficiency

Environmentally and ecologically friendly ship does not only mean more efficient ship, but also less pollutant ship. Prevention of pollution by inland vessels is generally regulated by various international and national rules (see UN ECE Resolution No. 21, for instance). As a consequence, vessels have to be equipped with appropriate technical means for collection, retention on board and transfer into reception facilities (shore based and floating) of waste generated on board. Appendix 4 indicates possible ship pollutants.

7.1. Improvements in Hull Resistance (with the aim to reduce R_T)

7.1.1. Ship form

As already stated in Section 3, vessel speed and length should be adapted to a particular waterway (water depth - see Figures 3.2 to 3.4). The secondary hull form parameters, mainly the form of the bow and stern, significantly influence resistance (see some shallow water designs - Figures 7.3 to 7.5). It should be stated, however, that a good, low-resistance hull form can be obtained only if advice of experts are followed, and often after model experiments are carried out in specialized towing tanks (which is not done so often), see Figure 7.2. As a result of experimentation, contemporary inland vessels can have lower resistance, in some cases even up to 50%, than those of few decades ago (Zoelner 2003).

Contemporary Computational Fluid Dynamics (CFD) techniques may be used as an efficient "tool" for resistance reduction, see Figure 7.2. CFD techniques, however, are also developed within scientific and research institutions and are not (yet) applied in the everyday engineering practice, so expert advice is again necessary.

Figure 7.2 Model tests of a push train – an example of good wave system optimised by Contemporary Computational Fluid Dynamics (CFD) (Source: MARIN)

In this context, the results of other related projects, for instance the VEBIS Project (Zibell and Mueller 1996) and "Inland ship of the future" (VBD report 1260) are very useful. In both projects, optimal units/hull forms for variable transport tasks and regimes of operation are investigated. Hints and recommendations for the design of inland ships for shallow water can be applied to vessels for the Danube waterway; see Figures 7.3 and 7.4. (small and large selfpropelled vessels) and 5.19 (pushboat).

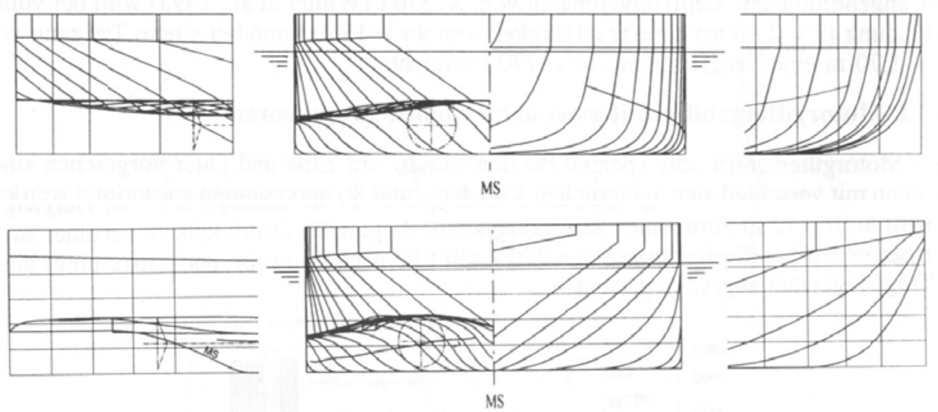


Figure 7.3 Twin screw ship (VEBIS Study: Type I and from it developed Type IV) - L=82 m, B=9.5 m, T=2.5 m, TEU 77, propellers in nozzles with conventional rudders

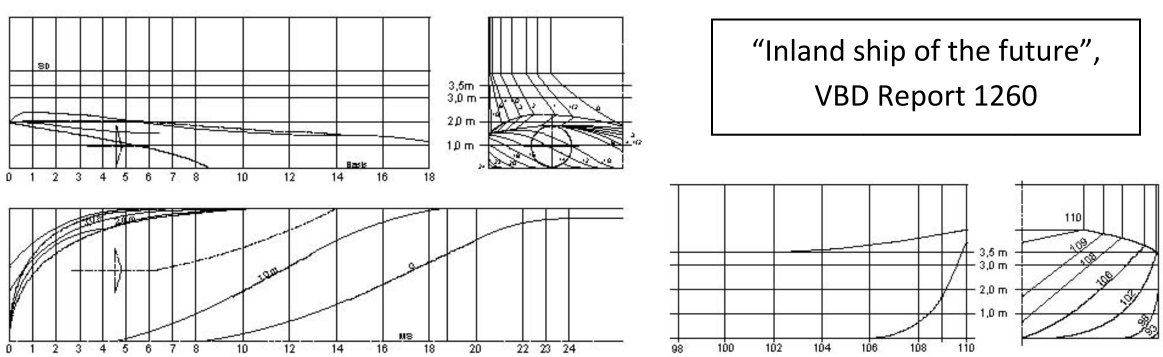


Figure 7.4 Example of the ship lines design (Source: SPIN Rhine)

Figure 7.5 Special attention should be paid to tunnel and skirt design to enable better water inflow to the propeller

7.1.2. Ship weight reduction

Low-speed inland vessels are made exclusively of steel and are very durable since their life is usually 50 years, often more. Hull construction of contemporary transport vessels does not differ much from those of few decades ago; hence their weight has not changed much. Possibilities to introduce “out-of-the-ordinary” materials targeted at hull weight reduction are low. The superstructure, for instance, could be built of aluminium or SPS (see below), or high tensile steel could be used for hull structure (see Section 5.1.1, selfpropelled bulk carrier “Sava Mala”), but reduction of overall weight would be relatively negligible.

For instance, GL Rules that are often used for dimensioning large self-propelled inland vessels pose a restriction that the ratio L/H should be less than 35 (if not, direct calculations are necessary). This actually stems from the Rhine vessels which, having larger draught than Danube vessels, also have a larger side height (H). L/H ratios for large Danube vessels, however, might be larger than 40, so direct longitudinal strength calculations have to be performed.

The so-called Sandwich Plate System (SPS) seems to be able to replace the traditional steel plate with secondary stiffeners. SPS consists of two plates with an elastomer injected between to form a solid unit (see Figure 7.6). The scantlings of SPS plating are generally in the range of 3mm to 8mm for steel face plates, and 15mm to 50mm for core thickness. Till recently scantlings could be determined only by direct calculations, however in 2006 Lloyd’s Register revealed “Provisional Rules for the Application of Sandwich Panel Construction to Ship Structure” – see Appendix 5.

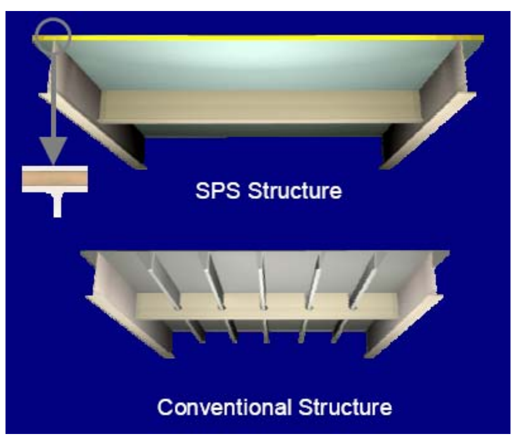


Figure 7.6 SPS vs. conventional structure (Source: www.ie-sps.com)

In the already mentioned INBAT project, a structural weight savings of around 40% was reported (Jastrzebski 1993) if steel sandwich panels (I-core^R) would be used for a small barge of 32.5 m (see Figure 7.7). It is stated that use of I-core^R panels simplifies barge production as well as maintenance (note that the I-core^R panel is somewhat different than the SPS analysed in Appendix 5). Other projects in which various kinds of SPS were investigated are: DE-LIGHT, LASS and CampoCaNord (selfpropelled barge of 65x5.8x3 m weighing ~75 t instead of 170 t, with a lifetime of 50 years and hull thickness up to 30 cm instead of 8 mm).

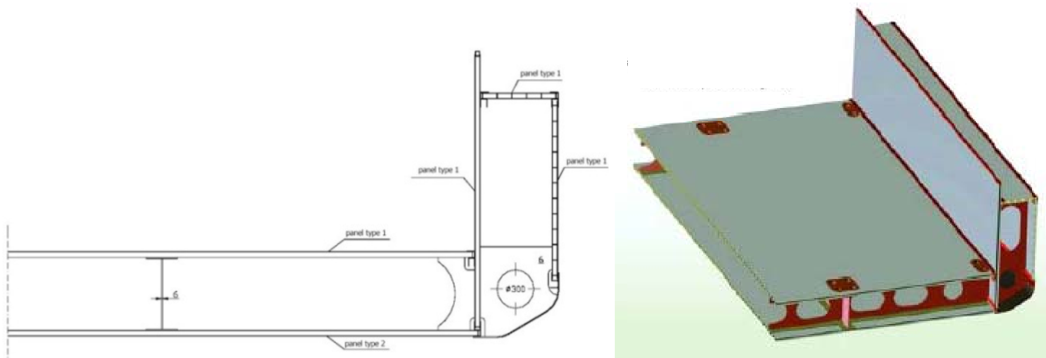


Figure 7.7 Typical frame cross section of an I-core^R panel barge (Source: INBAT Project)

As the above-mentioned savings of 40% appear attractive, and keeping in mind that LR Provisional Rules were recently published, custom calculations were performed especially for this study (see Appendix 5) on the application of an SPS construction for a typical Danube barge (77x11x2.8 m, Figure 7.8). According to the obtained results, a weight savings up to 10% may only be expected. It was also found, however, that the possibility for weight savings should first be examined for conventional steel construction, as in practice IWW barges are much heavier than required by the Classification Societies Rules.

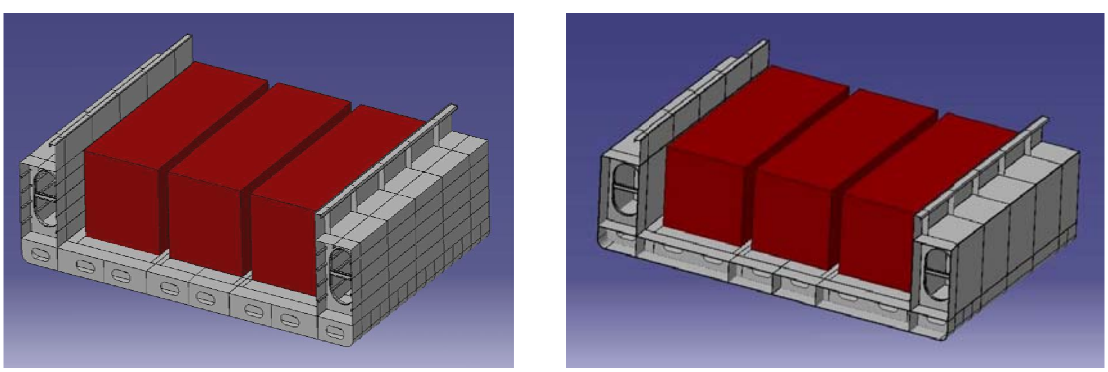


Figure 7.8 Cross section of conventionally structured and innovative SPS container barge

Nevertheless, SPS construction may have some other advantages (besides just weight savings), e.g. cheaper production and additional safety. For instance, the inner skin of an IWW chemical tanker inner plate could be built of stainless steel and the outer plate of conventional steel, using only 50% of the expensive stainless steel in current designs.

7.2. Innovations in Propulsion and Transmissions (with the aim to increase $\eta_D\eta_S$)

Propulsors that can be used on inland waterways (IWW), just for the purpose of this study, will be divided into two groups - **Screw Propellers** and **Other Propulsors** - rather than divided according to the principle how they work (as is usually done in the textbooks). Furthermore, having in mind their possible (practical) application, propulsors will be treated together with power transmissions, since they are often distinguished just according to the way power is transmitted from the engine to the propeller. For instance, both *pod propulsors* (electrical) and *rudder propellers* (mechanical) use the same type of propellers, but are somehow considered to be different propulsor types, although the difference stems only from transmission of power.

The way how the vessel has to be steered should also to be considered, since some propulsors inherently enable steering (rudder-propellers/azimuthing thrusters, for instance), while others need an additional steering device – a rudder. Vessel steering and manoeuvring capabilities are very important and belong to the safety measures which are required by various rules that should be satisfied. Consequently, steering devices are not going to be treated here, except that are mentioned as some propulsors need the rudder with adequate steering gear.

7.2.1. 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:

- **Fixed-pitch propeller - FPP** (or monoblock propeller) - there are several propeller types, and can have up to 7 ordinary or skewed blades (for reduced vibrations) - simple and cheap.

- **Controllable pitch propeller - CPP** – the thrust is controlled by changing the pitch, hence CPP can adapt to resistance variations (due to water depth, free-running or towing conditions etc.) - advantageous for faster vessels.

- **Propeller in nozzle (Ducted propeller)** - increases thrust if propeller diameter is restricted (thus heavily loaded) – usual case on IWW.

- **Contra rotating propellers - CRP -** two propellers turning in opposite direction (thus eliminating mutual rotating wake) - have the highest efficiency among all propulsors.

- **Tandem propellers** - two propellers turning in same direction - efficiency is between FPP and CRP.

- **Surface piercing propellers - SPP** - feasible for shallow water since only lower half of the propeller disc is immersed - still in design phase.

Combinations of the above are also possible, for instance CPP in a nozzle.

Since rivers are usually restricted in depth, propeller diameter will almost always be limited and therefore, a ducted propeller in a nozzle is necessary for majority of vessel types. There are various nozzle types; generally for slow speed and high thrust capabilities, a longer nozzle is needed, while for faster vessels a shorter nozzle should be considered. Consequently, fast vessels should use naked propeller.

7.2.2. Transmission of power

Transmission of power from the engine (prime-mover, usually a diesel engine) can be as follows:

- **Mechanical – horizontal** (traditional and usual case, rudder is necessary)
- **Mechanical – vertical** (azimuthing thruster or rudder-propeller, usually turns 360^{o})
- **Electrical** (Diesel-electric propulsion – (electric pod propulsor)
- **Hydraulic** (Diesel-hydraulic propulsion – (hydrostatic pod propulsor).

Accordingly, usual transmission losses from the engine to propeller are, respectively:

- around 4% (with gearbox),
- around 10% (gearbox + 2 pairs of bevel gears),
- 10-15% (energy conversion losses, mechanical-electrical-mechanical), and
- 15-20% and more (energy conversion losses, mechanical-hydraulic-mechanical).

Obviously, transmission losses from the engine to the propeller are high in some cases, which is often forgotten (note that in the last 50 years of propeller development its efficiency has increased by some 5% only; in that context it is pity to lose energy on transmission losses).

7.2.3. Propulsor steering capabilities

With traditional horizontal shafting arrangement, rudders are necessary, so to some extent they have to be treated together with propulsors. A rudder, or sometimes more than one, should be placed just behind the propeller in its slipstream. For better backward steering capabilities the flanking rudders, positioned in-front of a propeller, are often used (applied on river pushboats).

In all cases where the power transmission line is vertical (often called “Z-drive”), there is no need for rudders whatsoever, since these azimuthing thrusters provide complete directional thrusting capability by rotating around their vertical axis (usually 360 deg.). In general, enhanced steering capabilities of vertical shaft-line-thrusters have to be “paid” by breaking the shaft line itself, which results in reduced robustness and lower efficiency.

7.2.4. Innovative propeller-based concepts

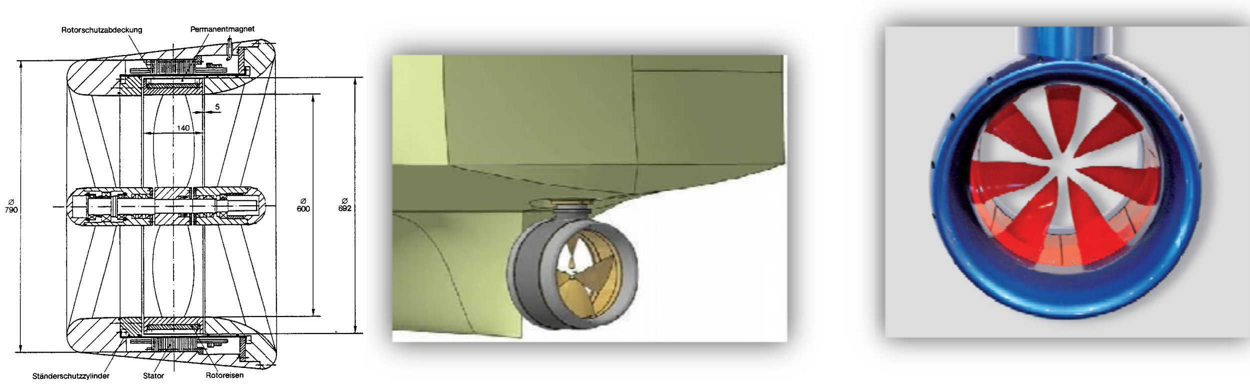
Pod propulsors (actually belonging to the family of azimuthing thrusters) incorporate an electric motor installed in the submerged pod. Probably the first units of the Azipod type used on inland waterways were on the Austrian river icebreaker "Roethelstein" (see Figure 5.16). Azipod is a trade name of the first pod propulsor on the market (produced by Finish Kvaerner Masa + ABB); it seems they are the only producers of compact pod propulsors. The well-known INBISHIP Project (Figure 5.18) was based on Azipods.

If power would be transmitted to the propeller via blade tips instead via boss (the usual case), then that would be a **tip-driven propeller** without classical shafts, which would have, amongst others, good unobstructed water inflow. A kind of 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), AEG-JASTRAM (Elektrischer Motorpropeller), General Dynamics Electric Boat (Rim-Driven Propeller - RDP), AIR/VETH (in line propulsor) and Brunvol. These new devices, most of them still in experimental stage, seem quite promising for application on river vessels (see Figure 7.9).

There are two types of electric, tip-driven propellers:

a) when bearings supporting the propeller axle are connected to the hull by means of strut arms (as shown in Figure 7.9.a) - *shaft-less* drive/propulsor.

b) when thin-section bearing is located in a nozzle. In this case there is no need for an axle or a propeller hub, so the propeller may be of a novel (unusual) design, Figure 7.9. b and c – this is both, *shaft-less* and *axle-less* or *hub-less* drive/propulsor.



a) b) c)

Figure 7.9 Tip-driven (rim-driven) electric motor propellers
(AEG-Jastram, Brunvol and Hub-less AIR/VOITH propulsors, some still prototypes)

Surface-Piercing Propellers (SPP) have only the lower half of a disc immersed in the water and therefore are suitable for shallow draft vessels. They are usually used for high-speed crafts, but recently AIR (now VOITH) started developing a slow-speed SPP-CPP which exploits the fact that SPP generates (beside the thrust) a large side force too, which enables steering, and hence a rudder is not required. Nevertheless, slow speed SPP are somehow clumsy (due to the large propeller disc whose bottom half only produces thrust) and have to be used in pairs (due to generated side force), Figure 7.10.

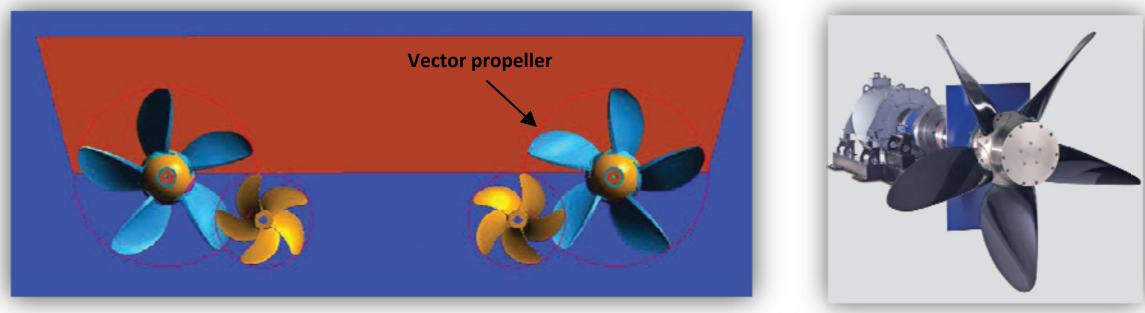


Figure 7.10 Size comparison of Vector and conventional propeller (Source: VOITH turbo)

7.2.5. Promising propeller-based propulsors

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

- **Propellers in nozzles** (FPP and CPP), with usual (mechanical) horizontal or vertical power transmission – Figure 7.11.a.
- **Tandem and CRP** with mechanical transmission – Figures 7.11.b and 7.11.c respectively.
- **Pod propulsors** (diesel-electric and hybrid with FPP) – Figures 7.12 and 7.13.
- **Combinations** of horizontal mechanical and azimuthing thruster, either one aside another with wing pod or rudder propulsors or similar (see Figures 5.22 and 5.24), giving good manoeuvrability, or one behind the other also giving good efficiency (working as CRP).

a) b) c)

Figure 7.11 Promising propeller-based propulsors – a) Rudder-propeller in an integrated nozzle (VETH FPP), b) Tandem propeller (Schottel Twin Propeller– STP) and c) CRP (Veth Z-Drive)

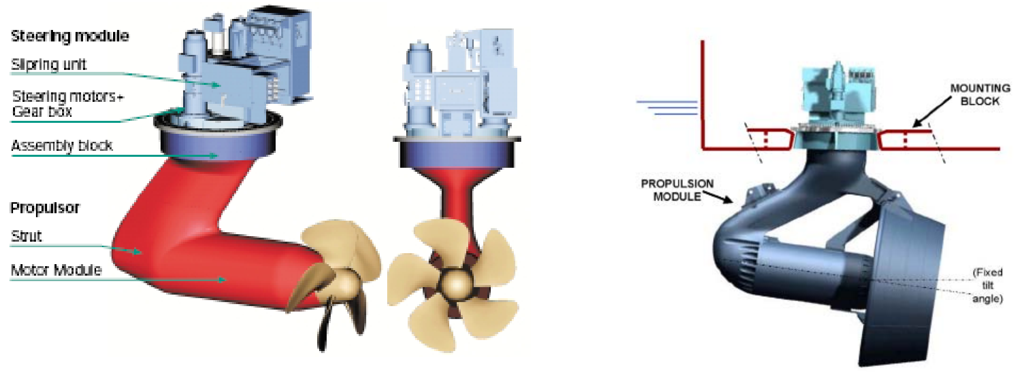


Figure 7.12 Compact Azipod drive (without and with a nozzle). A compact electrical motor is located inside the pod and is directly coupled to the FP propeller

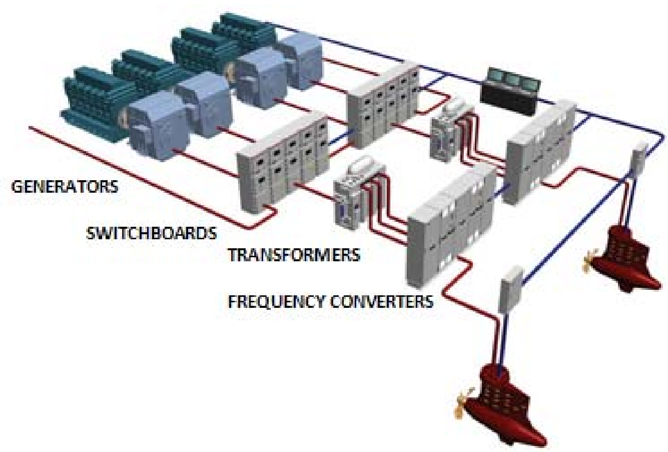


Figure 7.13 Azipod's electric propulsion and power plant

Similar to diesel-electric propulsion is **diesel-electric hybrid propulsion** (developed by Siemens under the trade name SISHIP EcoProp). As might be expected, the hybrid propulsion complies with stringent environmental requirements. It can also be integrated with alternative energy sources such as wind, solar or fuel cells. Amongst disadvantages, however, are the high investment costs and higher weight compared to conventional diesel-mechanical systems. It has some similarities with diesel-electric propulsion explained above, i.e. a sophisticated control system enables a) run of as many diesel powered generators as required to cover the power demand, b) diesel engines operate at optimum efficiency (independent of the required propeller shaft speed) and c) power generated is optimally distributed for propelling the ship and for other power demands. An additional feature, however, enables the batteries to operate in the following four modes:

- Diesel mode: Power from propulsion diesels drives a geared generator, feeds the ship service net, charges the batteries and propels the vessel.
- Battery mode: Electrical power from batteries feeds the ship service net and propels the vessel (for instance when anchoring, docking or manoeuvring at low speed).
- Electro mode: Power from a harbour generator charges the batteries, and supplies the ship service net and propulsion motors (for instance for cruising).
- Hybrid mode: Propulsion diesels drive the vessel with additional power from geared electrical motors that receive power from a harbour generator (for maximum power demand).

The SISHIP EcoProp electrical motors and other components are compact and standardized (ranging from 100 kW to 400 kW per shaftline and are used for road vehicles too). Electrical motors located in the ship are connected via the gearbox to a horizontal propeller shaft, see Figure 7.14 (this requires rudders, which are not needed when the electro motor is in the pod).

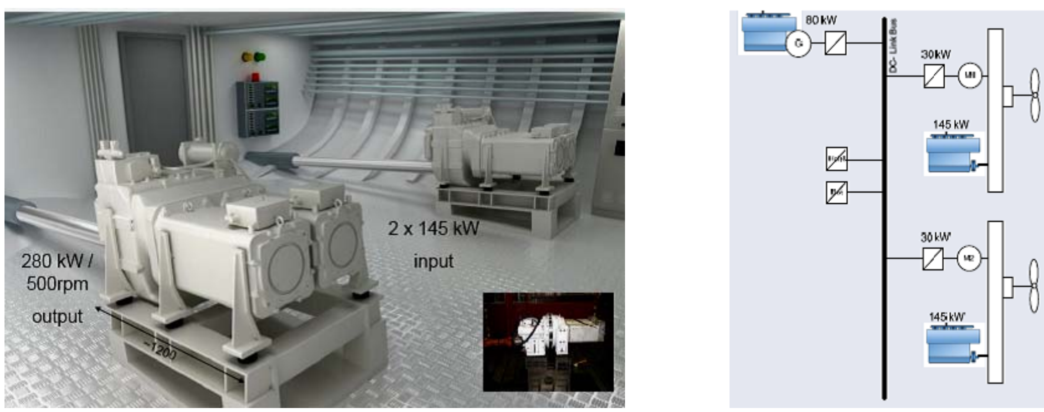


Figure 7.14 Pure diesel-electric propulsion and hybrid propulsion configuration (Source: Siemens)

7.2.6. Other propulsors

Not counting the clumsy side or stern paddle wheels (that require low RPM), which, by the way, have good efficiency and are inherently adapted to shallow draught (river) vessels, only three propulsors, other than propeller-based, will be mentioned here:

- **Waterjet or a Pump-jet**
- **Vertical propeller** (produced only by Voith and therefore often called Voith-Schneider propeller, sometimes Cycloidal propeller)
- **Whale or fish tale propulsors** (still in development phase).

Pump-jets, with a vertical axis are initially developed to be bow-thrusters, see Figure 7.15. They consist of a mixed-flow pump placed in a special volute casing which can rotate about its vertical axis, enabling steering throughout 360 degrees. Water is drawn into the casing below the hull and is expelled through the outlet nozzle. Advantages are applicability to very shallow draught vessels, good manoeuvrability, simple hull form, robustness (even grounding is allowed) and reduced jamming. The disadvantage of the Pump Jets are relatively high costs. Moreover, when operating in very shallow waters, Pump-jets may negatively impact the riverbed causing motion (redistribution) of sediments.

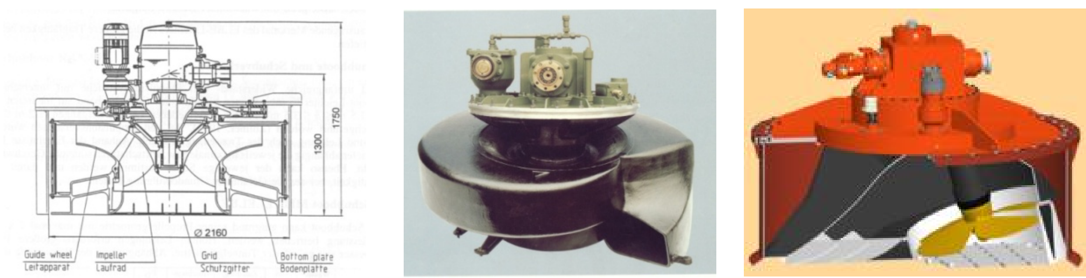


Figure 7.15 Schottel's Pump-Jet and Veth's Compact-Jet

A **vertical propeller** (Figure 7.16) might be used on vessels requiring very good manoeuvrability, since they can produce controllable thrust throughout 360 degrees. Nevertheless, vertical propellers are relatively complicated and therefore expensive. They are not as efficient (as ordinary propellers) since their vertical blades generate thrust only over a part of revolution at a cost of ever present frictional resistance.

The principle of the vertical axis propeller can be applied to a cycloidal propulsor having horizontal shaft as well. This is the basic idea of the **whale tail propulsor** (Figure 7.17) which is still in the development phase.

Figure 7.16 Vertical Voith-Schneider propeller

Figure 7.17 Whale tale arrangement (Source: CREATING WP5)

7.2.7. Rating of propulsors

An attempt was made to compare all mentioned propulsors on the same basis – see Table 7.1. Picking out just one of them and rating it separately, would, probably, bring to different conclusions from those given in Table 7.1.

Table 7.1 Propulsor applicability on a potential IWW vessel

No.	TYPE OF A PROPULSOR	Transmission type	Propulsive efficiency	Manoeuvring capabilities	Robustness	Extra space on a vessel	Cost of a propulsor	Built-in cost	Maturity (developing phase)	Environmental pollution
1	Naked FPP	M-Hor	-	- -	+ +	- -	+ +	+	+ +	-
2	Naked FPP	M-Ver	- -	+	-	- -	-	+ +	+	-
3	Naked CPP	M-Hor	+	-	-	- -	-	+	-	+
4	Naked CPP	M-Ver	-	+ +	- -	- -	- -	+ +	-	+
5	Ducted FPP	M-Hor	+	- -	+ +	- -	+	-	+ +	-
6	Ducted FPP	M-Ver	-	+	-	- -	-	+ +	+	-
7	Ducted CPP	M-Hor	+ +	-	-	- -	-	-	-	+
8	Ducted CPP	M-Ver	+	+ +	- -	- -	- -	+ +	-	+
9	Ring propeller	M-Hor	+	- -	+ +	- -	+	+	-	-
10	Steerable nozzle FPP	M-Hor	-	+	+	- -	-	- -	-	-
11	Tandem propeller	M-Ver	+	+ +	-	- -	-	+ +	+	-
12	CRP	M-Ver	+ +	+ +	- -	- -	- -	+ +	-	-
13	Slow speed SPP	M-Hor	?	?	?	+	?	+	- -	?
14	Pod propulsor FPP	E-Ver	- -	+ +	-	+ +	- -	+ +	-	+ +
15	Hydrostatic FPP	H-Ver	- -	+	- -	+ +	- -	+ +	- -	+
16	Tip-driven, shaft-less FPP	E-Hor	-	- -	-	+ +	?	+	- -	+ +
17	Tip-driven, hub-less FPP	E-Hor	?	- -	-	+ +	?	+	- -	+ +
18	Pump jet	M-Ver	- -	+ +	+ +	- -	- -	+	+	-
19	Vertical propeller	M-Ver	- -	+ +	-	- -	- -	-	+	+

Abbreviations:

Rating

++	very good
+	good
-	average
- -	bad
?	not known

Transmission types

M	mechanical
E	electrical
H	hydraulic
HOR	horizontal
VER	vertical

Note: HOR arrangements need a rudder (except in cases 10 and 13), while VER arrangements, just by rotating the propeller along the vertical axis, generate thrust in all directions, hence do not need rudder.

7.2.8. Improvement of Hull-Propulsor interactions

Large potentials for energy savings lay in improvements of interactions between the hull and a propulsor (i.e. propeller). As explained at the beginning of Sections 3 and 7, the intention is to increase efficiency of a propulsor - η_D (which depends on hull-propulsor interaction and is expressed through the so called propulsive coefficients). In other words, the aftship should be adapted to: a) particular propulsor, and b) the waterway (i.e. water depth which vary from one river stretch to another). So, aftship should be designed in such a way that advantages of navigation in deep water are fully exploited (with a relatively undisturbed inflow of water to the propeller), while maintaining possibilities of shallow water operation in partly loaded condition.

This can be realized with an adjustable tunnel (Figure 7.18, see also Figure 7.5), which is – depending on the draught – aligned with the hull (upper photo), or with fins folded downwards (lower photo) to prevent entrance of incoming air into propeller at low draught. Thus, the propulsion efficiency significantly increases at higher draughts as no parts, like with fixed tunnel forms, prevent water inflow. In addition, a ship with adjustable tunnel is able to operate at lower draughts than without it, thereby not jeopardizing propeller efficiency caused by air intake. Actually it enables a ship without a tunnel to operate efficiently under partly loaded condition too. Adjustable tunnel is not yet implemented in full-scale, only model tests were carried out in DST. Savings of about 10 % are expected.

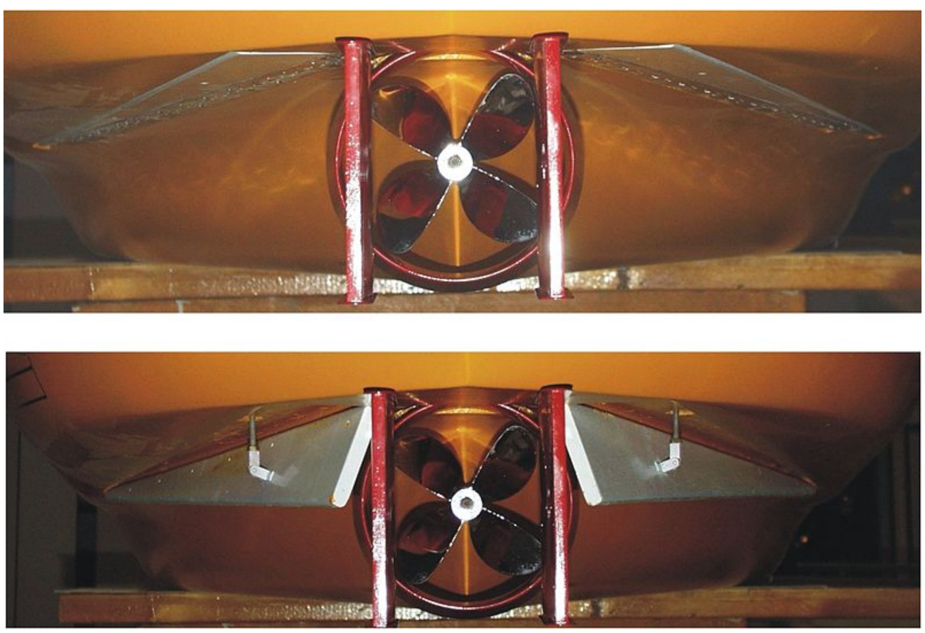


Figure 7.18 Adjustable tunnel for inland vessel
(Source: www.naiades.info/wiki/index.php5/Adjustable_tunnel)

7.3. Innovations in propulsion plants and fuels (with the aim to reduce fuel consumption and pollutant emissions)

7.3.1. Diesel Engines

Diesel engines dominate IWW nowadays. Modern engines that are nowadays used on inland ships are often marinized general-application diesel engines (generating-set engines having 1500 or 1800 rpm for 50 or 60 Hz, respectively) or are truck engines. Both engine types are much lighter and cheaper than their predecessors (that had 700-800 rpm), not to mention that they are an order of magnitude cleaner than the older ship engines. As a consequence, contemporary gearboxes have higher gear ratios than those of few decades ago.

According to some EST studies (Environmentally Sustainable Transport) it is not expected that major breakthrough technologies (concerning ship engines) will be made in the next 20 or so years. Furthermore, environmental considerations will, without any doubt, guide and force engine development. As the shipping industry is too small to drive the development of new types of propulsion plants, truck engines will probably have to be used as the prime movers on inland waterway ships in next decades. In the meantime, emission problems with diesel engines will become much more pronounced than is the case today.

7.3.2. Emission problems

Diesel engines (and fuels) are constantly developed with the aim to reduce harmful emissions (and consumption, of course). The quantity of the following substances in exhaust gases is relevant for evaluating diesel engine cleanliness:

- Carbon dioxide (CO_2)
- Carbon monoxide (CO)
- Nitrogen oxide, NO and NO_2 (NO_X)
- Sulphur oxides, SO and SO_2 (SO_X)
- Unicirated hydrocarbon compounds (HC_X)
- Soot particles (PM)

Among these, probably the most relevant single substance is carbon dioxide (CO_2) which contributes to climate change (global warming) – see Crist (2009).

Note that different abatement methods have to be applied for each component:

- CO_2 depends directly on the amount of fuel consumption
- NOx does not depend on consumption, but on design and state of the engine
- PM is mainly carbon particles (soot), and depends on maintenance and fuel type
- SOx depends on the type of diesel fuel (sulphur content of the fuel)

7.3.3. Exhaust emission legislation

In the EU, Non-Road mobile machinery (as are inland vessels) are regulated by Directive 97/68/EC, while in the US emission standards are managed by the EPA regulations for marine vehicles. These standards are constantly upgraded and in a way are “alive”. Regulatory authorities are asked/forced by engine manufacturers to harmonise worldwide emission standards for different markets in order to simplify engine development. As a consequence, EU emission limits for non-road machinery Stage I/II were harmonised (more or less) with the adequate US limits of Tier 1/2, and Stage III/IV with US Tier 3/4 standards. Stage III/IV standards apply only to new vehicles and equipment. Stage III standards are further divided into two sub-stages: Stage IIIA and Stage IIIB, see Figure 7.19. Stage IIIA standards, amongst others, cover engines used in IWW vessels, see Table 7.2. As a rough estimate it is predicted that Stage IIIA will reduce inland and coastal emissions by around 50%, but these benefits will take very long time to reach. At the moment, there are no Stage IIIB or Stage IV standards for IWW vessels, but it might be expected, by mirroring EPA regulations, that in the near future they will apply to IWW vessel too, see Figure 7.20.

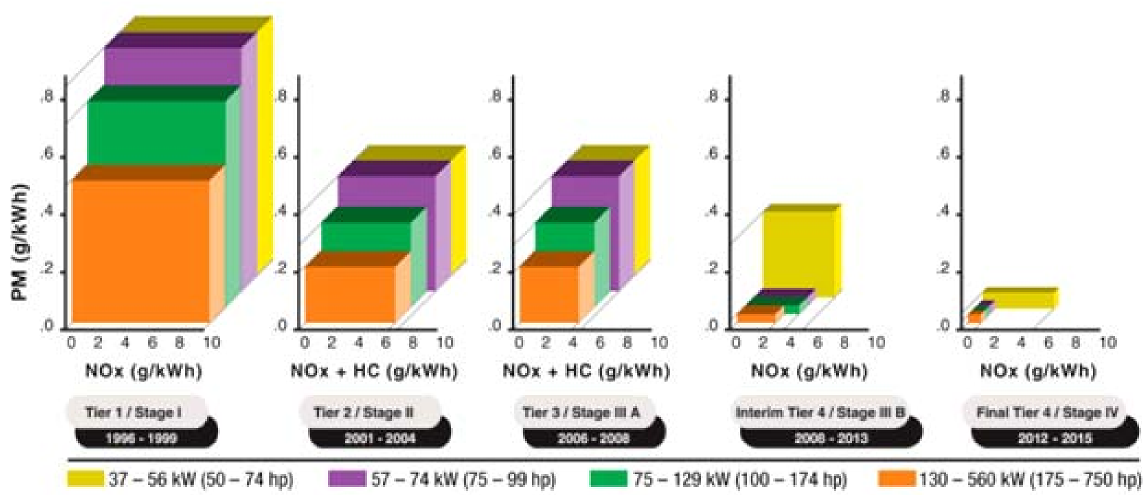


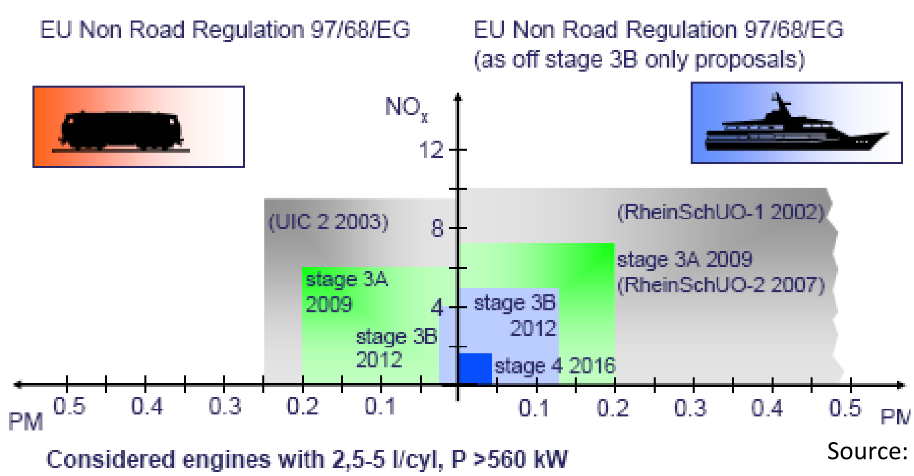
Figure 7.19 EPA and EU Non-Road emissions regulations (37-560 kW)

7.3.4. Findings from the CREATING project

Generally speaking, ship engines only have CO_2 emissions lower than the truck engines (due to lower consumption. See Appendix 6), while NO_X, PM and SO_X emissions are higher. The reason for this lies in different emission regulations for road vehicles (truck engines) and ships (ship engines), see Figure 7.21. Note that in this section CCNR norms are assumed to be relevant for IWT; CCNR II almost corresponds to EU Stage IIIA.

Table 7.2 Stage IIIA standards for IWW vessels
(Source: www.dieselnet.com/standards/eu/nonroad.php)

Cat.	Displacement (D)	Date	CO	NO_x+HC	PM
	dm³ per cylinder		g/kWh		
V1:1	D ≤ 0.9, P > 37 kW	2007.01	5.0	7.5	0.40
V1:2	0.9 < D ≤ 1.2		5.0	7.2	0.30
V1:3	1.2 < D ≤ 2.5		5.0	7.2	0.20
V1:4	2.5 < D ≤ 5	2009.01	5.0	7.2	0.20
V2:1	5 < D ≤ 15		5.0	7.8	0.27
V2:2	15 < D ≤ 20, P ≤ 3300 kW		5.0	8.7	0.50
V2:3	15 < D ≤ 20, P > 3300 kW		5.0	9.8	0.50
V2:4	20 < D ≤ 25		5.0	9.8	0.50
V2:5	25 < D ≤ 30		5.0	11.0	0.50



Source: MTU

Figure 7.20 EU Exhaust emission legislation – comparison of Marine/Mobile machinery

Obviously emission regulations for road vehicles (EURO) and IWT are different. In addition there is considerable time lag in implementation of EURO & CCNR emission regulations. Taking into account that ship engines are much older than truck engines and that they belong to previous technological generation (with a lifetime of at least 20 years for ship engines vs. 5 years for trucks), emission legislation becomes extremely important. The above-mentioned is actually the main reason ships are not as clean as previously claimed.

In the CREATING project (whose objective was to find solutions to improve the environmental performance of IWT) emissions were compared between IWW ships - a Rhine selfpropelled

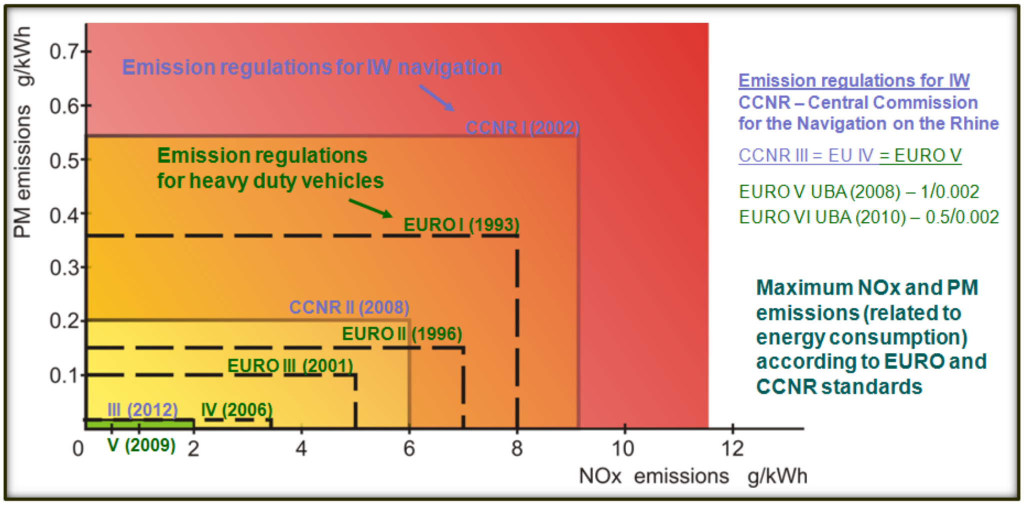


Figure 7.21 Emission legislation for road vehicles and ships

vessel, Danube Ro-Ro vessel and Danube coupling train - and a truck on the basis of tkm was evaluated. Surprising results were obtained, see Figure 7.22. Taking into account that fuel consumption per tkm of waterborne transport is roughly 1/3 of that of road transport, and that trucks have cleaner engines, follows that:

a) Ships are NOT so clean in terms of NOx and PM, unless Emission Reduction Techniques (ERT) are applied, and

b) Standards according to CCNR III (corresponding to EURO V) may be met only by application of ERT (in particular SCR+PMF+LSF) (see Figure 7.22 and Table 7.3).

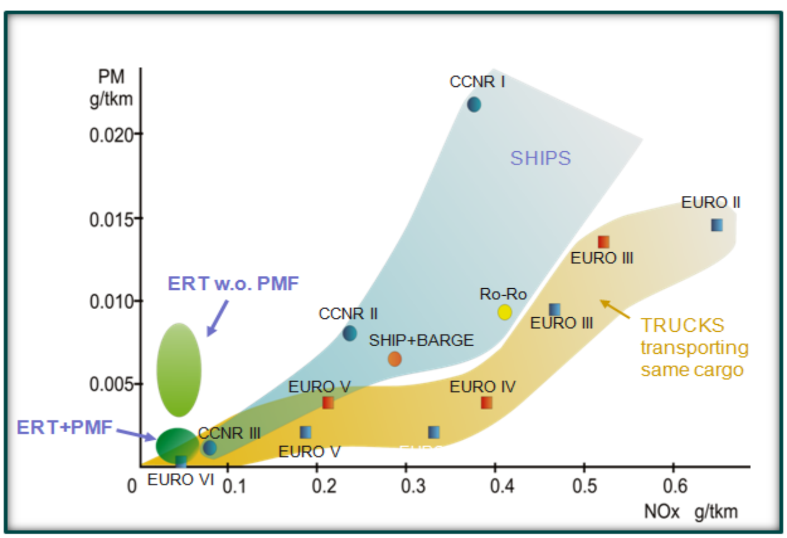


Figure 7.22 Emission comparisons between considered IWW ships and a truck on the basis of tkm

Emission Reduction Technologies - ERT consist of several compatible and complementary measures (Table 7.3):

- **First step** – Reduction of allowed sulphur for marine oil diesel
  Goal: 0.1% (which is still 100 x higher than for trucks), otherwise even IWT cannot compete with trucks in terms of emissions (this fuel is supposed to be available throughout the EU in 2011)
- **Second step** - Application of new diesel engine technologies and exhaust gas cleaning. Older engines should be retrofitted with after-treatment devices.

Table 7.3 Changes in mass emissions compared with a basic case without reduction techniques (CCNR 1)

	NO_X	PM	F.C.	CO_2	SO_X
After treatment techniques					
SCR	**-81%**	-35%	-7.5%	-7.5%	-7.5%
PMF	none	**-85%**	+2%	+2%	+2%
Drive management system					
ATM	-10%	-10%	**-10%**	-10%	-10%
Diesel fuel quality					
BD	+10%	-30%	+15%	-65%	-100%
BDB	+2%	-6%	+3%	-13%	-20%
LSF	none	-17%	none	none	**-100%**
New engine techniques					
NGE	-98.5%	-97.5%	+4.5	-10%	-100%

SCR – Selective Catalyst Reduction
PMF – Particulate Mass Filter
ATM – Advising Tempomaat
BD – Biodiesel
BDB – Biodiesel Blend (80% fossil + 20% BD)
LSF – Low Sulphur Fuel
NGE – Natural Gas Engine
F.C. – Changes in Fuel consumption

So, to get the "climate-friendly" IWW Ship according to:

- CCNR III (corresponds to EURO V) from a CCNR I ship, it is necessary to apply SCR + PMF + ATM + LSF (see Table 7.3). According to the CREATING project, this greening on IWW should be stimulated by financial interests (investment cost of application of SCR+PMF+ATM+LSF is supposed to return in ~3 years). It should be noted that application of just biodiesel (BD) is not sufficient, and its application is controversial anyway. Note that old ship engines will prolong implementation for ca. 20 years!
- For EURO VI emissions, similar fuel & engine technology as truck engines is necessary (which brings new problems), or a completely new engine technology (Natural Gas Engines, Fuel Cells …) should be applied.

Within the CREATING project, the Demonstrator – "the cleanest ship ever" – was supplied with the above-mentioned technologies. This was the low-emission, fuel efficient and environmentally-friendly BP motor tank vessel "Victoria" (60x11.45 m, 1300 t, with MTU 880 kW/1800 rpm). Exhaust figures as well as savings, which are constantly upgraded, can be found at www.cleanestship.eu/charts and are based on 3000 operational hours per year, an average delivered power of 70% and a fuel consumption of 203 g/kWh. The undertaken measures were:

- Low sulphur "EN 590" fuel (equal to road standard) was used – reduces SOx & PM
- A PM & SCR catalyst in the same reactor (selective catalytic reduction & soot filter) was implemented, produced by *Hug Engineering* – reduces NOx & PM
- ATM (the Advising Tempomaat) produced by *Techno Fysica* enabled optimal operation of the vessel – reduces CO_2

Regarding the same subject, Schweighofer & Blaauw (2008) and Schweighofer & Seiwerth (2007) papers should be also consulted.

7.3.5. Innovations in propulsion plants

Possible innovations are depicted in Figure 7.23. Note that darker parts of the table mean short or medium-term applications, while white ones are medium and long-term niche applications. Actually, the darker parts were explained above, while the white parts – diesel-electric, gas engines and fuel cells – deserve further discussion.

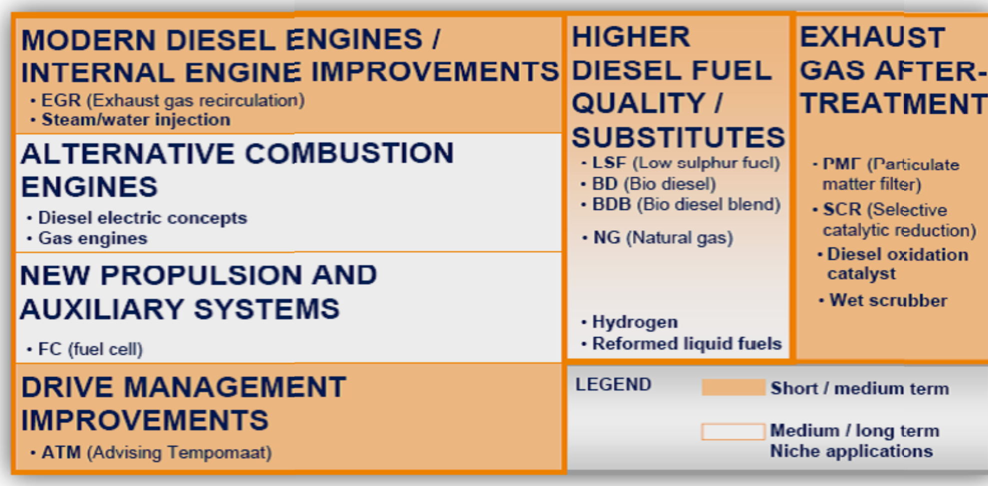


Figure 7.23 Innovations of propulsion plants and fuels (Source: CREATING project)

Diesel-electric concepts are not so far in the future; they are already applied on sea vessels and on the IWW icebreaker "Roethelstein" (see Figure 5.16). This concept was also applied in INBISHIP project (see Section 5.2.1 and Figure 7.13).

Natural gas engines (NGE) are actually diesel engines that, instead of ordinary fuel oil, use liquefied natural gas (LNG). The necessary engine adaptations for LNG are present day technology and the main problem is safe fuel storage onboard (or within) the ship itself (to be in liquid form gas has to be cooled and pressurized). Compared to conventional diesel engines, NGE are more efficient and have lower environmental impact.

Fuel cells (FC) are nowadays used on submarines, while R&D work is focused on road vehicles and stationary power plants, but the goal of zero emission is driving development of hydrogen FC and hydrogen storage methods. FC are electrochemical devices which convert the chemical energy of a fuel (for example hydrogen or natural gas) into direct current power. Bureau Veritas (BV) recently published guidelines for safe application of FC on ships. Concerning commercial ship application, various types of FC are in the research/experimental phase.

Within the INBAT project, FC power was examined (see Zenczak et al. 2003) for a low-draught pushboat and was compared to variants of diesel power plants. Regarding weight, FC power is comparable to a conventional ship power plant with a mechanical transmission, however, the cost of FC was considerably higher than other engines that were considered.

Within the EU supported Life-project Zemships (Zero Emission Ship) the first FC powered passenger ship FCS "Alsterwasser" was developed (Figure 7.24). She was designed as a mono-hull ship with two fuel cells of 50 kW and a carrying capacity of 100 passengers. The ship is fuelled by hydrogen, which is stored on board at a pressure of 350 bar. The ship is 25.5 m long and has a draught of 1.2 m. The vessel has been sailing on the Alster in Hamburg since August 2008. FCS “Alsterwasser” is regarded to be the first IWW passenger vessel where FC are used for the main propulsion. Beside Zemship project, there are other projects on FC applications on maritime vessels, as for instance MOST’H, FelowSHIP, FCSHIP etc., all with a goal to obtain a near-zero emission ship engine. Consequently, there are also a number of reports available on the internet.

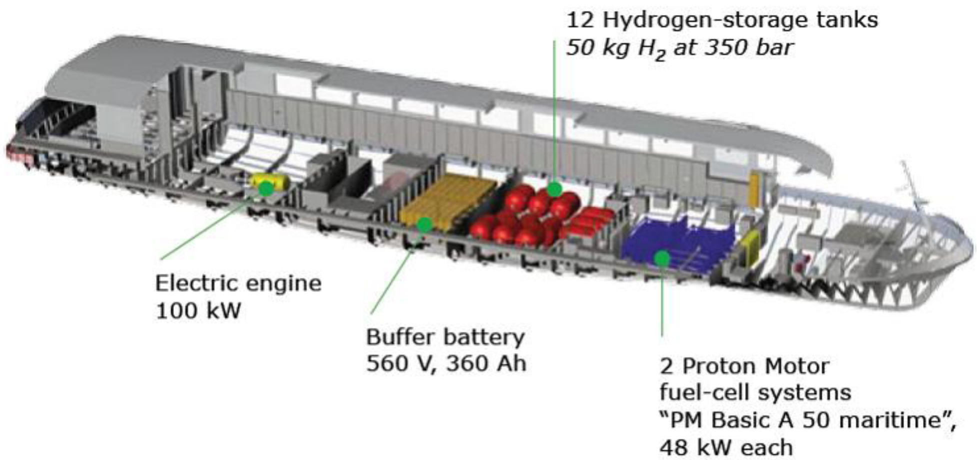


Figure 7.24 The FCS “Alsterwasser”
(Source: www.naiades.info/wiki/index.php5/Zemships - Zero Emission Ships)

7.4. Innovations important for better ship utilisation/navigation (with the aim to reduce ship speed and increase cost-effectiveness and safety)

River Information Services (RIS) provide possibilities for voyage planning, tracking and tracing, both from vessels and from shores. Improved communication and information exchange within the system indirectly contributes to the optimisation of 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 skippers on another, giving relevant information about the ship (her position, speed, destination, cargo etc.). According to received information, a skipper can calculate the estimated time of arrival (ETA) to a certain destination, and, if possible, reduce/adjust ship speed. Amongst others, this might result in 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 the 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 the 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 were a further step towards the full implementation of the RIS on the Danube River. Moreover, the EC prepared the so-called RIS Directive, which sets-up a legal framework for River Information Services in Europe.

Concerning the Danube, RIS technology is already used on the Austrian sector of the Danube and certainly will be used on the whole Danube in the near future.

On board computerisation and RIS application (Figure 7.25) in addition to **crew training** can lead to so-called eco-sailing (equivalent to eco-driving which is nowadays widely applied throughout Europe resulting in fuel reductions of 5 to 10%). For instance, in Holland, the Ecodriving Programme Voortvarend Besparen ("Saving While Sailing") was initiated with the goal to reduce fuel consumption and pollutant emissions from inland vessels (part of the Dutch Air Quality Action Plan, see www.voorvarendbesparen.nl). According to DNV, shipowners can reduce air emissions up to 15% from ships, using available technology on today's ships without incurring additional costs!

Figure 7.25 Bridge computerization on river vessel (Source: Witteveen-Bos)

7.5. Concluding remarks

In order to achieve more efficient and cleaner IWT, contemporary logistics concepts should be applied. Transhipment should be cheap and fast, and the waterborne part of transport should be efficient. Concerning the last item, besides the measures that often do not depend on ship design (crew costs, taxes, loan and fuel costs), the following is necessary (according to Figure 7.1):

a) Reduction of total resistance
b) Increase of propulsion efficiency
c) Reduction of fuel consumption
d) Reduction of ship speed (if possible)

Of course, other aspects of ship design should not be forgotten, i.e. safety measures and cheap production. To achieve this goal it is necessary to obtain the following (according to the conclusions of each sub-section of chapter 7):

- In order to maximise the gains and minimise the costs, it is important to involve the hydrodynamic expertise at an early design stage. Often a good, low-resistance hull form can be obtained only if model experiments are carried out in specialized towing tanks.
- Weight reduction is possible not only by applying the latest technologies (like SPS), but in the first place by not unreasonable accumulating the additional weight by thickening the hull structure more than rules are requiring.
- To obtain good propulsion efficiency, new propulsors should be considered (see Sections 7.2.5. and 7.2.7).
- New engine types should be considered for ship applications, most probably derived from general application diesel engines or road vehicles. Exhaust emission legislation measures are important for cleanness of ship engines. Figure 7.26 depicts PM and NOx emissions for EURO, CCNR and Stage IIIA standards. The precondition for low emissions is, however, low sulphur fuel. CO_2 emissions charges could become effective in the near future (i.e. fuel cost might include environmentally relevant surcharges based on SO_X and CO_2), so low emission engines will pay off in shorter period of time.
- For better ship utilisation, command-bridge computerisation is necessary through application of RIS and other contemporary IT achievements. But above all, crew training is necessary (particularly on the Danube) that would result in higher safety measures and better eco-sailing capabilities. According to DNV ships from all market segments can reduce their air emissions by carefully analyzing and optimizing a number of individual operations, such as optimizing engine performance, optimizing trim for all drafts and speeds and the

propulsion system efficiency and improving voyage management. Actually, all aspects of ship operations should be thoroughly reviewed in order to increase efficiency and reduce emissions.

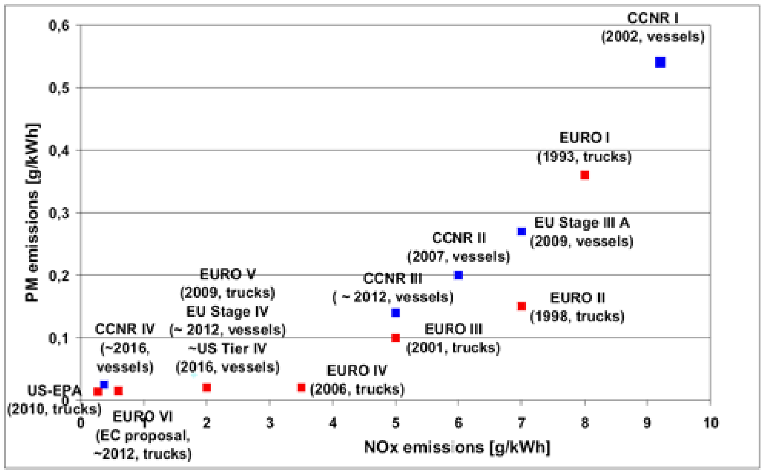


Figure 7.26 PM and NOx emissions for EURO, CCNR and Stage IIIA standards (Source: CREATING Project)

Most of the measures mentioned above may be and should be applied for all new buildings. Nevertheless, the majority of existing old and often not-well maintained vessels can benefit by applying some of the above-mentioned measures. Note that the Danube fleet is on average 20 years younger than that on the Rhine, but is by far in worse shape due to unacceptable negligence and lack of regular maintenance (Figure 7.27).

Figure 7.27 Tug boat, Belgrade, 2008

8. CUSTOM DESIGNED VESSELS FOR THE DANUBE RIVER

With the aim to demonstrate how a contemporary, safe, cost-effective, shallow draught vessel intended particularly for the Danube waterway should look like, some of the conclusions and technical achievements aimed at increasing efficiency of inland navigation, and discussed in the previous sections, will be incorporated into design of two specific ship types:

- Selfpropelled container vessel
- Barge train (actually a pushboat) for bulk cargo.

These two distinct ship type concepts are chosen because they are good representatives of typical ships used on the Danube. This does not mean that selfpropelled vessels are assigned just for the container transport or barge trains for bulk cargo, nor that innovations integrated into one concept cannot be applied in the other. Concepts would be able to operate on the navigable tributaries, RMD waterway and other canals, naturally with certain restrictions that are given in Table 2.3 and Figure 2.4.

Needless to say, but new vessels have to be built (hence designed and operated through its lifetime) in compliance with various international and national rules and regulations. This is, per se, a guarantee that the vessel will be safe and environmentally acceptable (see Appendices 4 and 7). Also, it is usually underlined that a ship and her equipment will be made *according to good shipbuilding practice and experience, standards of the yard etc.;* those phrases, however, do not mean much as they are not so compulsory, although they are said worldwide.

Concepts will be followed with a section on possible conversions and retrofitting measures with a similar purpose, i.e. to show application of new technologies on already existing vessels.

8.1. Selfpropelled ship for transport of containers

Special attention was paid to existing navigation conditions on the Lower Danube, but as it might be expected that the container vessel would operate on the whole Danube, restrictions of the Upper Danube were also taken into consideration. An optimised vessel, in general, was briefly explained in Section 2.1, restrictions of the Danube waterway in Section 2.3 and its implications on ship design in 2.4. The cargo that should be transported - intermodal loading units (ISO containers and EILUs), their size etc. are explained in Section 4.2, while main characteristics of conventional selfpropelled vessels suited for the Danube waterway are given in Section 6.

8.1.1. Proposed features of a Danube container ship concept

The objective here is to explain (in words) how successful shallow water container vessel could look like. Therefore, the recommended vessel dimensions and other important characteristics to be incorporated into design are the following:

- **Draught (T) – 2.5 m maximum** for three layers of full containers of average mass of 13 t (see Figure 6.2). With two layers of full containers, draught will be **up to 1.85 m**. Nevertheless, according to transport statistics, on average 2/3 of all containers are loaded and 1/3 are empty (with a mass of ca. 2 t only). Therefore, it might be expected that in reality draught will be smaller than stated above. If reduced draught sailing would be necessary, a coupling train should be considered.
- **Breadth (B) – 11.65 m (cargo hold breadth just above 10.3 m)** allows abreast loading of four ISO containers or 2.50-2.55 m wide domestic containers - EILUs (see section 4.2). Note that the usual ship breadth is up to 11.45 m (due to locks and gangway restrictions), but keeping in mind the extensive use of pallet-wise EILUs within Europe (other transport modes are using them) and that the competitiveness of IWT should be increased, a ship width of 11.65 m is suggested (although locks on the Upper Danube are 12 or 24 m wide, see Table 2.2 and 2.3). Note that for the Rhine corridor the breadth of 11.65 m was requested, but is not allowed yet. Concerning the Danube, downstream of Vilshofen the allowed breadth could be anything up to 23.4 m (see Section 2.4), but keeping in mind that the larger the breadth is, the larger ship resistance and wave wash is. A breadth of 11.65 m was chosen as a good overall compromise.
- **Length (L) – 104 m** follows from the desired **cargo hold length of around 80 m**. Within this length, longitudinally 13 TEUs may be stowed with 20-50 mm clearance between them (this requires top-lift transhipment with a spreader). A hold length of 80 m allows also a wide variety of other stowing possibilities, for instance (6x40’ + 1x20’), (4x45’ + 4x20’), (4xA1360 + 4x20’), (9xC745 + 2x20’), etc. Discussion given in section 6.2 (long or beamy vessel) and 7.1.2 (L/H ratio) explains why the longer ship is not recommended. Furthermore, with this ship length, a coupling train with a standard 77 m Danube barge would be shorter than 185 m (see Table 5.1).
- **Height (H) – 3.1 m**. This is a discussible subject and is beyond the scope of this study. Namely, freeboard (F) of 0.6 m and safety clearance of 1000 mm (i.e. hatch coaming height of at least 400 mm) is suggested for Zone 3 (the Danube) and for the vessels of type C (open hold vessels) - see UN-ECE “Amendment of the Recommendations…”, GL and similar rules. Nevertheless, taking into account some recent disasters due to insufficient safety clearance (see Hofman et al 2006) **F = 0.6 m and a coaming height of 1.1 m** is suggested, which is more than required by the rules. Besides, H=3.1 also satisfies GL suggestion for L/35.

- **Ship form – should be optimised for low resistance navigation in shallow water**. The form should be relatively full (both C_B and C_P around 0.9), with full fore- and after-body providing substantial buoyancy (hence allowing larger payload) at low draughts. This, however, will inevitably increase resistance. After body is strongly influenced by propeller diameter and propulsor type (twin rudder-propellers of relatively small diameter are imagined here). Ship form should mirror weight distribution (accommodation in the front, engines at the stern) which should reduce the trim of partly loaded ship. The above-water bow form should be adapted for pushing (coupling train formation). Note, however, that hull form optimisation with the purpose to reduce resistance requires model testing (see section 7.1.1).
- **Ship weight – should be reduced by around 10% compared to conventional designs** by applying state-of-the-art technologies, probably high tensile steel for the hull structure (see section 5.1.1 vessel “Sava Mala”), SPS or aluminium for superstructure. Capital weight savings, however, should not be expected, but overall weight savings within the classical steel-building approach might be obtained (see Section 7.1.2). Although somewhat opposite to the weight savings, ballasting is often necessary, so ballast tanks should be considered too.
- **Propulsion – two rudder (azimuthing) propellers in nozzles with D≈1.35 m** optimised for both low draught and full draught operation, see Sections 7.2.3 to 7.2.5. Propulsors may be **a)** of innovative design, for instance **diesel-electric with Azipods** (INBISHIP concept, see section 5.2.1 and Figures 7.12 and 7.13), or **b)** conventional mechanical **“Z drive” rudder-propellers** (see Figure 7.11). Both will eliminate the need for rudders and will also enable exceptional manoeuvring capabilities. If diesel-electric propulsion is envisaged then an innovative tip-driven propulsor might also be considered (see Section 7.2.4 and Figure 7.9). A **bow thruster of around 250 kW** (with the ability to assist stopping and improve thrust – four-channel) either diesel or electrically driven, should be considered.
- **Engines – low emission diesel engines satisfying Stage IIIA/Tier 3 norms or better** (see Section 7.3.3) with relatively high power to weight ratios should be considered. If diesel-electric propulsion would be applied (Azipods), then a power of around **4x400 kW** is suggested; for mechanical rudder propellers around **2x700 kW** or so would be sufficient. Power is estimated for an assumed speed of 16 km/h, as well as a coupling train formation with one, probably two Danube barges (depending on waterway conditions). Diesel-electric propulsion is ecologically very attractive, but is also more expensive than mechanical transmission. Near zero emission FC or similar (see Section 7.3.5) shouldn’t be expected to be seen on IW vessels in next decade or two. Nevertheless, in future diesel-electric sets may be replaced by FC, so electrically driven rudder-propellers (of Azipod type or tip-driven/rim-driven) might be regarded as the propulsor of the future.
- **Shore-to-ship-power supply** (of electricity while in port, often called *cold ironing*) should be considered with the aim to reduce on-board diesel emissions.

- **Accommodation, wheelhouse and engine room.** All crew premises should be dimensioned according to UN-ECE Recommendations based on six crew members and should be positioned in the bow (the wheelhouse too), while the engines (placed in well insulated spaces) should be at the stern. This enables good visibility (hence safety too), crew comfort (no vibrations and noise) and a well-balanced ship at low draughts.
- **Electronics** and computerisation should of latest generation, providing a **one-man bridge system** including a data-based ship monitoring system (engine and ship-system monitoring and recording, voyage optimization, etc.); see Section 7.4.
- **An on-board crane with a capacity 35t/30m** should be considered as this would allow transhipment at any port (see Figure 5.5). However, this would reduce the number of containers that could be transported.

It should be noted however that the shipowner, according to his own requirements, judgments of the market trends and costs, usually requires a specific ship to be designed/built (having particular dimensions, carrying capacity, engines, equipment) and that "design freedom" as exercised above is very seldom. For instance, ship speed, which is amongst the most influential design parameters, was omitted in this discussion.

8.1.2. General arrangement plan of a container ship concept

A General Arrangement (GA) plan of a container ship concept is shown in Figure 8.1 and its enlarged bow and stern parts, in Figures 8.2 and 8.3, respectively. Two additional variants of the same concept are depicted in Figures 8.4 and 8.5. Namely, diesel-electric propulsion and a conventional mechanical (azimuthing) rudder-propeller may be employed – see Figure 8.4. An on-board crane is depicted in the GA plan, Figure 8.5 (with a mechanical transmission already shown in Figure 8.4) resulting in reduced carrying capacity, see below. The main particulars of the abovementioned vessels are the following:

		Configuration	
		Basic	**With a Crane**
Loa	m	104.0	102.5
Boa	m	11.65	11.65
H	m	3.1	3.1
T	m	2.5	2.5
Hold length	m	80.0	78.5
Hold width	m	10.34	10.34
Height above basis line	m	8.3	8.3
P_B	kW	4 x 400	2 x 700
TEU (3 layers / 4 layers)		156/208	134/172
Payload capacity	t	1950	1800

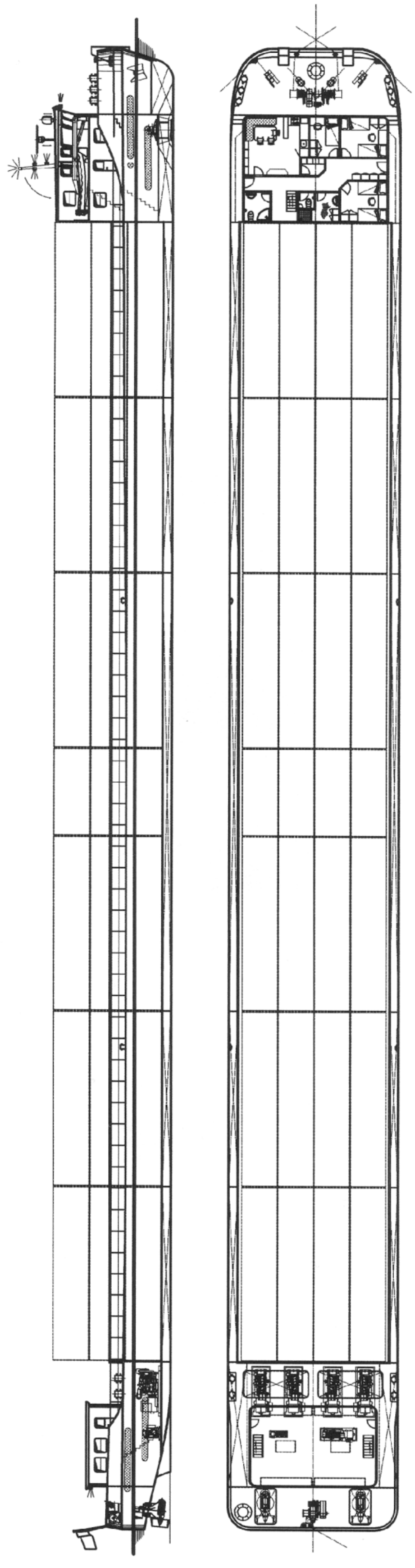


Figure 8.1 General Arrangement plan of a container ship concept – diesel-electric propulsion

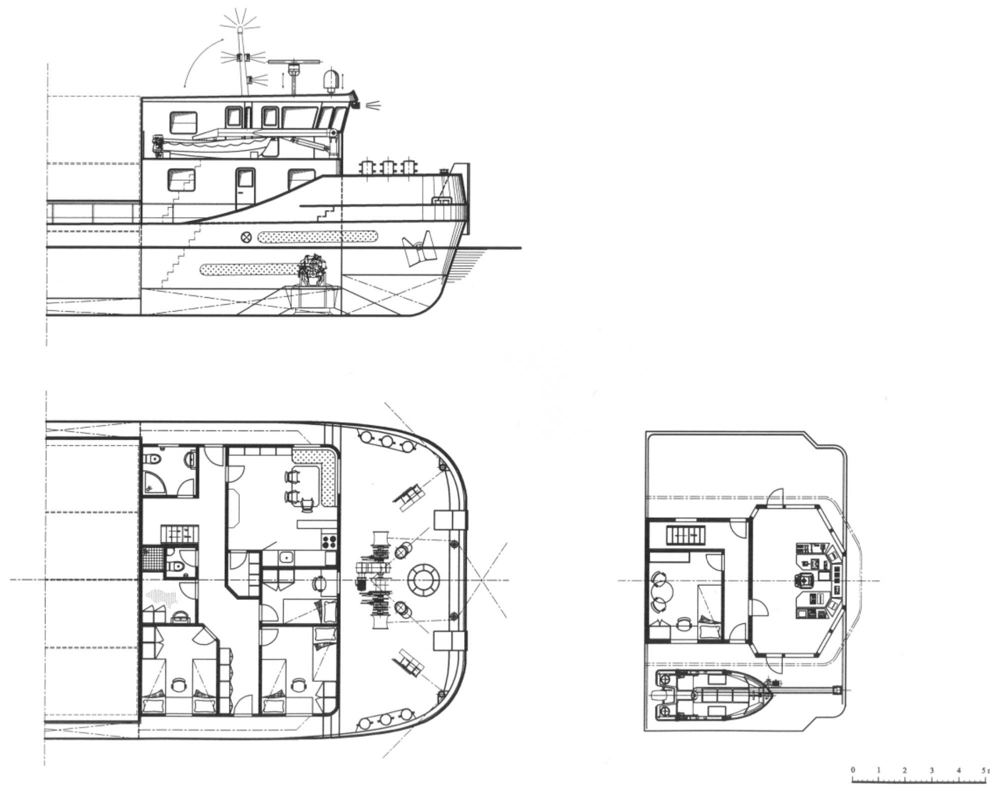


Figure 8.2 Enlarged bow part (both variants)

8.1.3. Advantages of a concept compared to conventional ships

Some of the concept's features (underlined below) suggest an environmentally acceptable vessel with a large volume and payload capacity. At the same time due to superior manoeuvring capabilities, the proposed concept should be safer than similar selfpropelled vessels on the Rhine and Danube. So:

- **Special attention was paid to low-draught performance**. Consequently, the proposed concept should be able to operate successfully and therefore be cost-effective at both low **draught of up to 1.7-1.8 m** (with two container layers) and **full draught of up to 2.5 m** (with 3 layers of full containers or even 4 layers of mixed full and empty containers).
- The chosen **hold length (80 m) and breadth (10.34 m) allow stowing of a variety of 2.50-2.55 m wide domestic containers** (EILUs of C745 and A1360 type), besides the usual ISO containers (TEUs and FEUs). By the way, the same hold length and somewhat narrower breadth has contemporary MGS, which is 110 m long (vs. proposed 104 m). The concept's overall dimensions **104x11.65 m allows passage through all Danube locks**, even in coupling train formation.

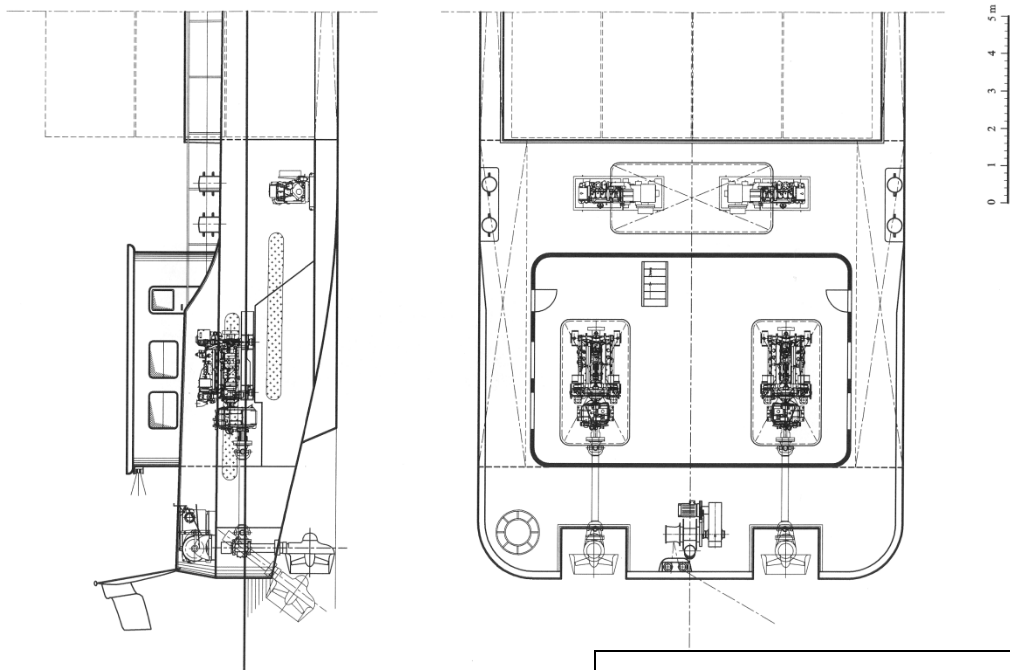


Figure 8.4 Enlarged stern part – variant with conventional “Z drive” rudder-propellers

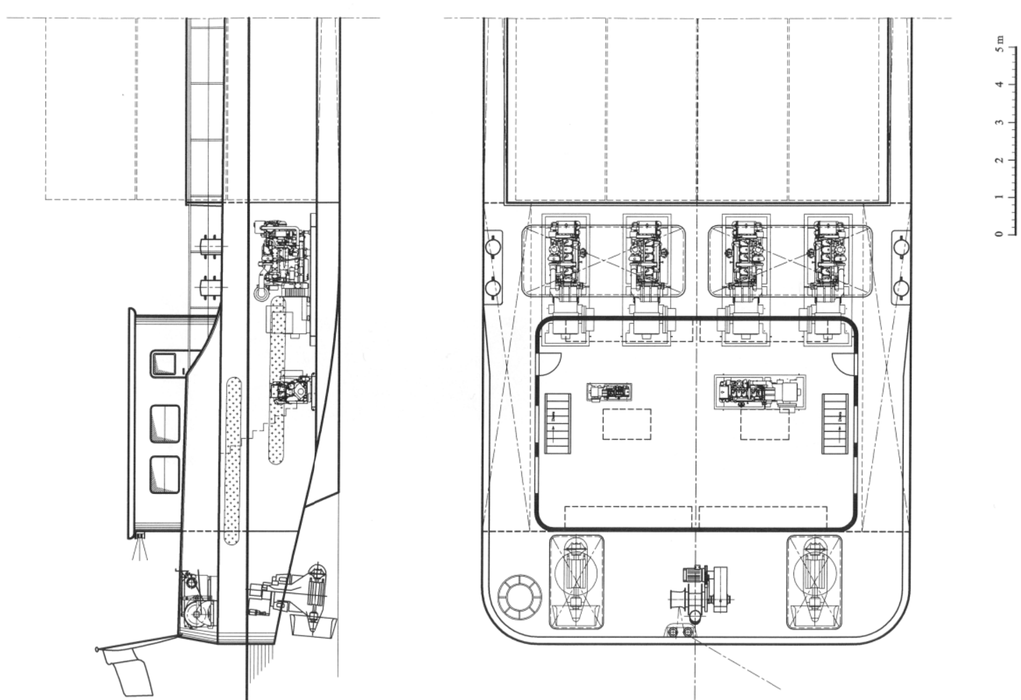


Figure 8.3 Enlarged stern part – variant with diesel-electric propulsion

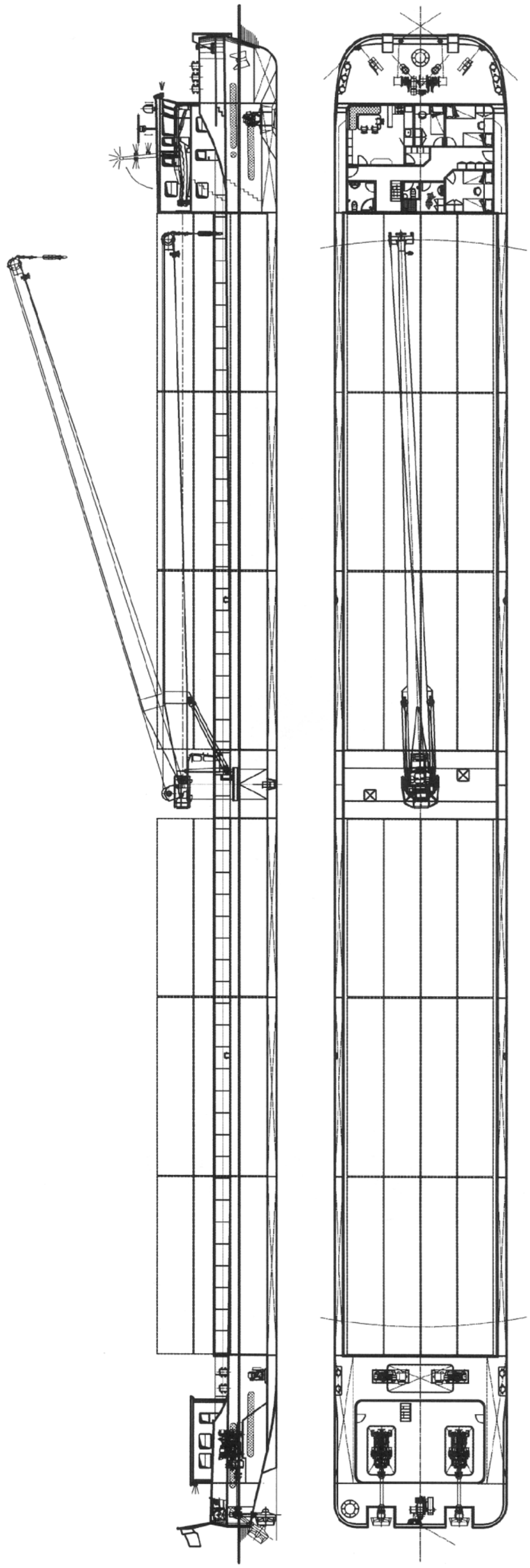


Figure 8.5 GA plan of a container ship concept – variant with conventional rudder-propellers and onboard crane

- An **on-board crane would allow transhipment at any port** which would be an advantage particularly on the Middle and Lower Danube where adequate container ports (hubs) and dedicated container transhipment equipment are rare. However, this would reduce the number of containers that could be transported.
- **Rudder propulsors enable exceptional manoeuvring characteristics** (steering & stopping) even at low draughts, resulting in a safer ship. If **diesel-electrical propulsion** would be installed, then additional benefits would be evident, i.e. better adaptation to various operation/sailing modes (upstream/downstream, speed and coupling train formation requiring employment of 1, 2, 3 or all 4 diesel engines). This would also **reduce fuel consumption** (probably by 10% in upstream and even more in downstream navigation), therefore emission levels would be lower as engines would run at optimal RPM/loading. For refrigerated containers and other large electricity consumers (a bow thruster for instance), the same electrical network could be used, eliminating the need for auxiliary units. Conventional, mechanically-driven rudder-propellers have the advantage of being cheaper and retractable (hence can better adapt to water depths).
- The position of engines/engine room at the stern and the crew premises at the bow offers **additional crew comfort** (reduced vibrations and noise). Application of contemporary equipment and electronics enables safer sailing and lower overall operational costs.

8.2. Barge train for transport of bulk cargo

The main advantage of a push train, or barge transport, compared to selfpropelled ship transport, is that cost-effective navigation with reduced draught with partly loaded barges may be utilized. Usually it is the draught of a pushboat that poses the main problem, as it cannot be reduced below a certain level (the transom and propellers should have designed minimal draught, otherwise they cannot work properly). Conventional Danube pushboats with a power of around 2000 kW usually have draught of more than 1.7 to 1.8 m, meaning that this draught is actually a limiting factor. Due to that, pulling technology was never completely abandoned on the Danube as towing vessels have lower draught (usually below 1.5 m) and are therefore used during the dry seasons. Consequently, a low draught pushboat with a power of around 2000kW would be more than advantageous on the Danube.

If navigation with a reduced draught would be required, then to substitute for reduced carrying capacity, the number of barges in a convoy might be increased; power needed for pushing this convoy would not increase proportionally (see Section 5.1.2); this is the main advantage of pushboat technology). Suggested power of around 2000 kW would be sufficient for sailing along the whole Danube at usual push train speeds with up to six fully loaded Danube barges (with a carrying 1500 to 1600 t each). Tonnage capacity at reduced draught of a typical Danube barge (77x11x2.8 m) follows:

T [m]	~0.5	1.0	1.5	2.0	2.5
Tonnage [t]	-	300-400	700-800	1100-1200	1500-1600

Note that according to the ToR, vessels for bulk cargo and container transport should be suggested. Therefore, a selfpropelled vessel (Section 8.1) was designed particularly for container transport, and a barge train was designed for bulk cargo, although discussions that follow would be the same for other cargo (general cargo, containers etc.), the only limitation being the draught of barges and of a pushboat.

8.2.1. Proposed features of a pushboat concept

- **Draught (T) – 1.4 m maximum.** Larger draught would certainly be desirable from a hydrodynamic point of view, but if there is a need to push a convoy at extremely low waters (see Section 2.3.2), then 1.4 m is probably the maximum allowable draught. With the abovementioned draught, a propeller in a nozzle with a diameter of 1.5 m could accept power of up to 700 kW, making a three-propeller installation feasible. Furthermore, a standard Danube barge with a draught of 1.5 m will carry a bit less than 800 t, which is approximately half of the carrying capacity of a fully loaded barge at 2.5 m. It is a discussible subject, but sailing at a lower draught than 1.5 m would probably not be cost-effective. From this point of view, the pushboat's draught of 1.4 m is also justified. Obviously the choice of draught is the most important technical compromise in pushboat design.
- **Triple-screw propulsion, (skewed) propellers in nozzles with a diameter (D) of 1.5 m,** should be located in a relatively shallow tunnel. A somewhat larger propeller diameter would be allowable (and desirable), but taking into account the limited breadth of 11 m and high-speed diesels, it is believed that 1.5 m would be just sufficient. With an engine power of 700 kW, propeller loading would be 375 kW/m^2, which is high, but is still acceptable. Special attention should be paid to the design of tunnels, propellers and a nozzles with the aim to increase ahead and astern thrust and reduce vibrations (model experiments are recommended).
- **Breadth (B) – 11 m**, which is the same as a standard Danube barge. A somewhat larger breadth would not be so harmful, as the pushboat is usually pushing a much wider barge convoy. Even if only one barge is pushed, a somewhat wider pushboat (than a barge) would not be so disadvantageous. Barge packing, however, is easier if both the pushboat and a barge have the same width. Nevertheless, if draught is limited, then either the length or a width (or both) should substitute the needed buoyancy. Consequently, it was decided to fix the breadth to 11 m.

- **Length (L) – of around 30 m**, under the condition there is enough space for all necessary machinery and crew. A somewhat longer vessel (if B and T are fixed) would be acceptable. With L=30 m, the overall length of a convoy of two barges and a pushboat would be 2x77+30=184 m, which is still acceptable for passing through Danube locks (see Tables 2.2 and 5.1).
- **Height (H) – 2.5 m** is considered to be minimal for fitting engines and other necessary machine-room equipment below the deck.
- **Weight** (dry) is estimated to be 270 t taking into account lightweight engines and other equipment and machinery. A larger value might compromise the draught and therefore the project itself. A fully loaded pushboat with fuel and other provisions should be around 350 t (at a level draught of 1.4 m). Weight saving should be considered wherever possible (SPS technology might be employed for the superstructure).
- **Ship form,** and particularly the tunnels, is of utmost importance as relatively large power needs to be installed within an extremely shallow draught hull (see Figures 5.19 and 5.22). The transom and propellers should always have a draught of around 1.4 m, while weight variations (due to fuel consumption) should change the trim and bow draught only. Model experiments are recommended.
- **Propulsion plant - Low emission diesel engines of 3 x 700 kW, satisfying Stage IIIA/Tier 3 norms or better** (see Section 7.3.3) with relatively high power to weight ratio should be considered. Transmission of power should be via **conventional horizontal shaftline** and a gearbox (with somewhat higher reduction ratio), see Section 7.2.2. Main engines and gensets should be flexibly mounted to the motor girder to reduce noise and vibrations levels. With installed power of around 2000 kW sailing along the whole Danube with a push train of six fully loaded barges (at T=2.5 m, carrying around 1500 to 1600 t of cargo each) at usual convoy speeds is possible during most of the navigable season. Expected fuel consumption would be around 10 t/day.
- **Shore-to-ship-power supply** (of electricity while in port, often called *cold ironing*) should be considered with the aim to reduce on-board diesel emissions.
- **Steering** – **three fish-tail rudders** located behind propellers (without flanking rudders, see section 7.2.3) and a **gondola type bow thruster** (with electrical motor) of around **300 kW** should be considered.
- **Provisions – for max 7 days**, meaning that 70 t (around 85 m3) of fuel should be provided. Nevertheless, although on the Danube it is accustomed to carry relatively large quantities of fuel (often for a roundtrip), much smaller quantities and refuelling on the way should be considered as overall situation within the New Europe has changed. Carrying smaller quantities of fuel might be a cost-effective measure.

- **Crew members – 8**, according to UN ECE Recommendations. Accommodation premises should be in one-tier superstructure on the deck (comprising 4 single and 2 double cabins, although this depends on the shipowner's needs/request). Living premises should be fully air-conditioned. Resiliently mounted superstructure (on pneumatic shock absorbers) for reduced vibrations, noise and increased comfort should also be considered (however that would require somewhat different cabin arrangement than given on the GA plan).
- **Wheelhouse – with the possibility to be raised** to increase visibility to at least 250 m, as requested by UN ECE Recommendations. When lowered maximal height above water level should be below 6.3 m, allowing sailing below all Danube bridges (except to on the Upper Danube at HWL, see Table 2.2).
- **Electronics** and computerization should be of the latest technology, providing one-man watch operation of the vessel with engine and ship-system monitoring and recording, voyage optimization, etc.; see Section 7.4.

Everything else should be as usual on a pushboat of this size, intended for navigation along the Danube River. Nevertheless, modern lightweight equipment and materials should be considered wherever possible, as larger weight (displacement, hence draught) than predicted can easily compromise every pushboat.

8.2.2. General arrangement plan of a pushboat concept

The General Arrangement (GA) plan of a pushboat concept is shown in Figure 8.6. The pushboat's main particulars are the following:

Loa	m	30.0
Boa	m	11.0
H	m	2.5
T	m	1.4
Height above basis line	m	6.0
P_B	kW	3 x 700
Bow thruster	kW	250-300
Crew		8

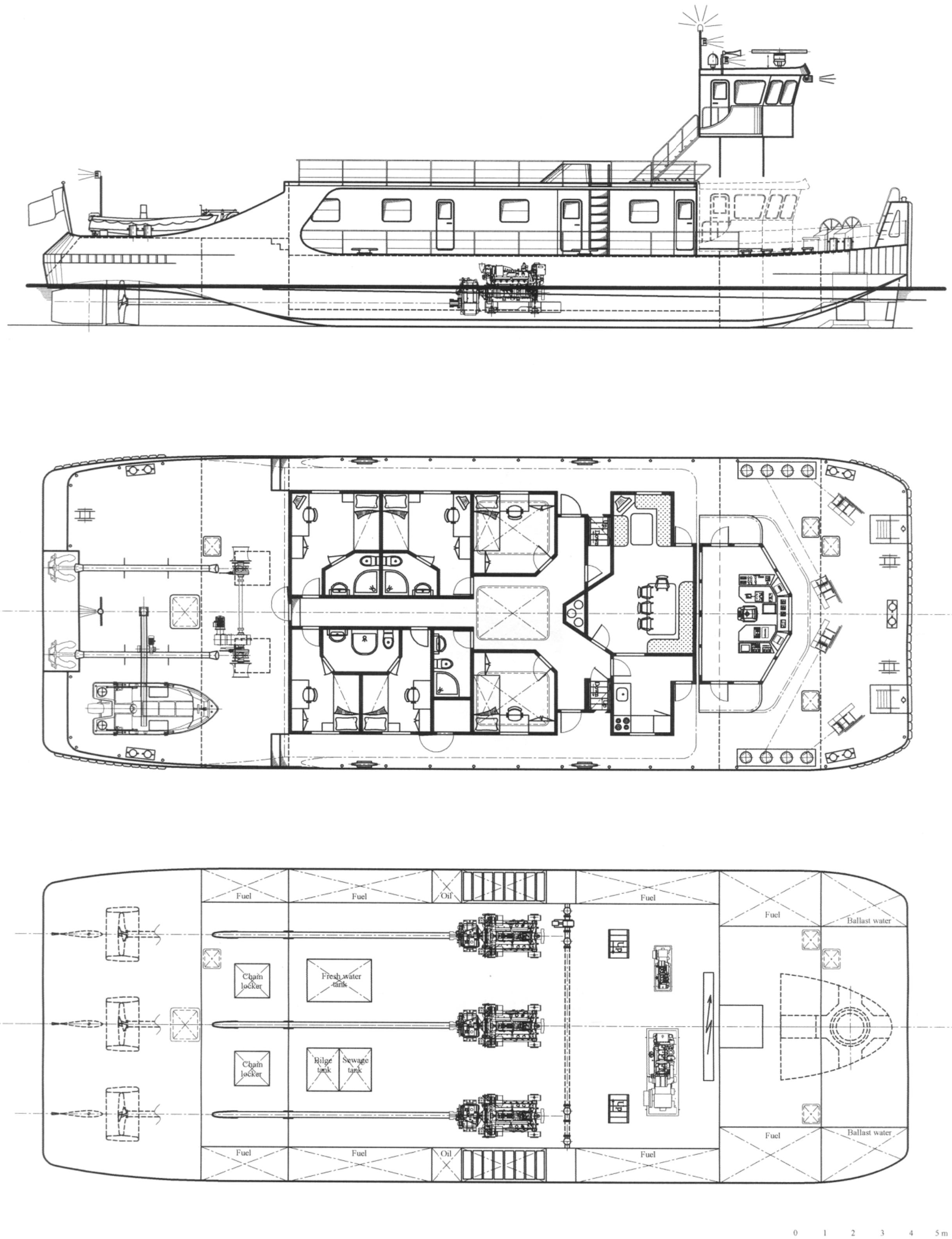


Figure 8.6 General Arrangement plan of a pushboat concept

8.2.3. <u>Advantages of a concept compared to conventional pushboats</u>

- The main advantage of the proposed pushboat is its **extremely low draught of only 1.4 m** (compared to draught of above 1.7 m of similar conventional pushboats). This enables navigation with partly loaded barges on the whole Danube even at LNRL.
- A gondola-type **bow thruster of 250 - 300 kW enables enhanced manoeuvring capabilities**, eliminating the necessity for conventional flanking rudders. Due to absence of flanking rudders, **unobstructed water inflow to the nozzles** can be achieved (hence higher efficiency), which is very important particularly for highly loaded propellers (due to limited propeller diameter, which is a result of draught limitation).
- **Application of the latest technological achievements that increase efficiency, safety, cleanliness and comfort** (for instance: clean engines, the advising tempomaat, RIS equipment, resiliently mounted superstructure etc.). Nevertheless, these benefits are not a result of the proposed pushboat concept, but rather of a modern era. Namely, almost all Danube pushboats were built 30 or so years ago and therefore were equipped according to the standards belonging to the previous technological generation, so a newly built pushboat of any design or concept will be advantageous compared to the old (conventional) ones.

8.3. Conversion and retrofitting measures that can lead to greener navigation

First of all, gradual phasing out of older vessels should be considered. An **old for new policy** was applied on the Rhine, so similar measures with experience gained so far on “the pattern River Rhine” should be considered to be employed on the Danube too.

The list of conversion and retrofitting measures with the aim to modernise existing vessels is endless. Only some of them - those that reduce fuel consumption - are mentioned below (according to Zigic 2006):

- **Replacement of old (usually medium speed) with new (usually high speed) engines** – this needs a new transmission gear too! In the first place maintenance costs are reduced, but fuel consumption and pollutant emissions are reduced as well.
- **Replacement of propellers/nozzles or whole after-body** (when propulsors are damaged so repair is not viable), or when engines are replaced. New stern+propellers+engines can reduce consumption up to 13%.
- **Lengthening of a hull (middle-body) or rebuilding of the cargo hold by implementing new technologies** with the aim to reduce weight (with employment of SPS for instance).

- Artificial (and cheap) modification of pre- and/or aft-body of a pushing ship and pushed barge to form a **"stump-end" connection** (Figure 8.7) may reduce exploitation costs by around 5%. Still, this measure is seldom applied. Accordingly, formation of push-trains (stump-end connection) would also be cost-effective.

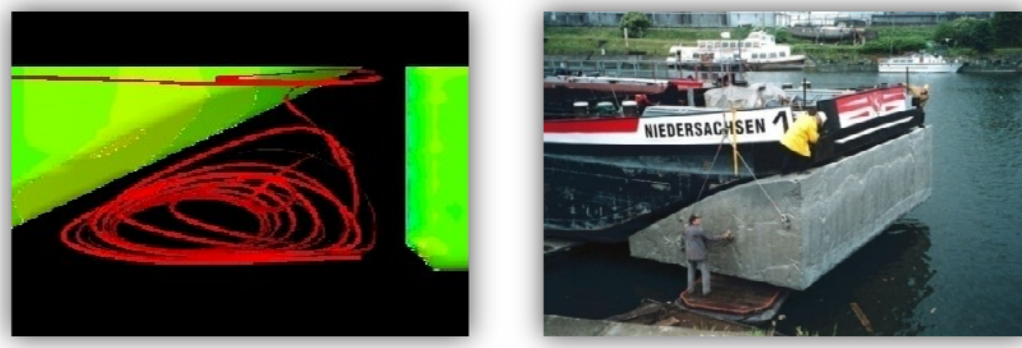


Figure 8.7 Full scale tests with a polyurethane wedge to match stump transom of a barge (Source: DST)

Note that other kinds of measures might be undertaken too (for instance those which enhance manoeuvrability and safety, enable vessels to comply with new rules etc.). Nevertheless, some essential features of existing vessels often cannot be changed, nor their characteristics noticeably improved, whichever reasonable technical measures would be applied.

8.4. The cost of newbuildings

The expected cost for building the selfpropelled vessel and pushboat concepts are around 5-6 million and 4-5 million Euros, respectively. These, however, to a great extent depend on chosen equipment, shipyard, material (steel) cost, time of order etc. Therefore, variations of order of magnitude of around 10 to 20% to the abovementioned might be expected. By the way in order to reduce production costs inland vessels nowadays are usually built in two or more companies. Typically the hull is built in a lower cost area, such as Serbia or China, and then is completed in the Netherlands or Germany where costs are higher.

Retrofitting and conversion costs are impossible to be anticipated as they depend on several factors. Note however that due to a) inadequate safety and environmental policy (once vessels are built and exploited), and b) general durability of river vessels and their equipment, shipowners often incline to various retrofitting or conversion possibilities rather than scrapping and building new vessels. Consequently, an old-for-new policy/scheme should probably be initiated on the Danube.

9. CONCLUSIONS

Concluding remarks were drawn after each Section, so there is no need to repeat them again. Moreover, all of Section 8, ending with the custom designs of two typical Danube vessels – selfpropelled and pushboat concepts, is a kind of conclusion, as most of the innovations and benefits mentioned in previous sections were incorporated in the new designs.

It should be underlined, however, that contemporary (modern) shallow draught vessels, particularly suited for the Danube waterway, are feasible and desirable. The only problem is that inherently they will be less efficient and less cost-effective (if water is deep enough) than the vessels with deeper draught (see Figure 2.1). Besides, IWT (river vessels) in general have very strong competition from other modes - railway and road transport, so under the present circumstances there may be a limit (concerning low draught navigation) under which IWT will not be cost-effective anymore, as other modes (already much stronger and better positioned) will prevail. On the other side, when there is not enough water (when LNRL) low draught vessels will have a logistical advantage compared to deeper draught pushboats, as will be able to navigate all the year round.

Consequently, under which conditions IWT will work (i.e. what would be minimal/guaranteed water depth along the river and throughout the season, cost of fuel, taxes, eventual state subsidies etc.) is a political question which should also be influenced, amongst others, by the technical and ecological requirements of IWT. Ships were navigating in the past, often transporting a larger quantity of cargo than today (on the yearly basis) although navigational conditions were worse (with a lot of shallows and free-flowing sectors, see for instance Figure 9.1), but the business environment was different than it is today (with pipelines, railway and road infrastructure passing through the Danube corridor).

Figure 9.1 Towing with the assistance of rail locomotives in Sipski kanal, Danube km 944 + 2200 m, right bank (current speed up to 18 km/h), from 1918 till the beginning of 1970 (when Djerdap dam was built) (Source: www.tk-info.net)

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APPENDICES

APPENDIX 1

The OECD Publication *Inland Warerways & Environmental Protection*, whose summary follows, is regarded important as "… assesses the ways in which the EU Water Framework Directive affects the planning environment for international waterways and sets a new agenda for improving the ecological value of waterways. The report makes recommendations on good practice and identifies the Danube river basin as the critical area for improvement. This is where the efforts of international governmental organisations and NGOs could most usefully be combined to develop a basin-wide environmental protection and waterway development strategy".

The environmental impacts of inland waterway development

Environmental impacts

Inland navigation can contribute to making transport more sustainable, particularly where it substitutes for road transport, but inland shipping and especially the development of waterways for navigation can have considerable environmental impacts. Waterway development works for inland navigation can have significant impacts on the ecological value and water quality of water bodies. The nature and extent of the impacts depend on the kind of works concerned and, to a large degree, on the characteristics of the water body itself. The kinds of mitigation techniques that can be employed can also differ markedly, for example between sections of river with rocky bed and banks, and reaches with sandy or muddy bottoms situated in flood plains. In some cases new works for navigation can be designed to improve water quality or biodiversity and create valuable habitats.

Hydro-morphological pressures

Foremost among the potential impacts are hydromorphological pressures. Altering the shape of river courses to improve navigation1 affects bottom and bank characteristics and the dynamics of sediment transportation. Effects can spread up- and downstream over many years. Without careful attention, alterations can interfere with communication between the main channel, side branches and backwaters. Permanent changes to water levels and flows affect the whole river valley bottom and notably the ecology of floodplains. Although it is often difficult to separate works strictly necessary for navigation from those designed for flood protection, navigation works tend to be designed to stabilise channels in both space and time. This constrains the natural dynamics of the river that create and renew transitory habitats that can be of intrinsic ecological value. Thus impacts on biodiversity can be substantial.

EIA must cover all impacts

Dredging sometimes has severe impacts, especially when sediments are contaminated with industrial discharges. Bank reconstruction can completely transform or remove habitats. It is essential for environmental impact assessment (EIA) to cover all of these pressures.

Avoiding damage

In many cases civil engineering works can be designed to minimise impacts, but hydromorphological pressures are sometimes unavoidable. Their ecological impacts are often site-specific and not always well understood. In some cases impacts may be negligible but often significant ecological damage can result. Hence there is a need to identify risk areas at a strategic planning level, and employ a detailed EIA at the project level when works are planned in these areas. Governments need to be ready to support research in cases where little or no information on hydromorphology and ecosystems is available.

Reconciling the promotion of navigation and environmental protection

Early consultation

Careful design can often mitigate impacts, and in several case studies it allayed concern over the environmental impacts of investments in infrastructure for inland navigation. Early consultation with environmental stakeholders, and indeed all stakeholders, is important in ensuring that such solutions are found. It is equally important to reach a common understanding of the issues and foster a co-operative search for solutions if the environmental impacts of a project prove not to be amenable to conventional mitigation approaches. In the case studies examined, all conflicts identified stemmed from failure to involve environmental stakeholders early enough in project planning. Expensive procedures were then required to seek compromises after lengthy and costly delays.

Strategic planning at river basin level

Strategic plans for the development of river basins that integrate economic, social and environmental imperatives could facilitate consensus building on individual development projects. The Water Framework Directive (WFD) provides a strategic planning basis for this in terms of water quality objectives, and has created a valuable tool through the establishment of river basin management plans. The Birds and Habitats Directives and Natura 2000 sites operationalise the strategic imperative to preserve sites of international importance to wildlife. There are no equivalent legal instruments to direct the development of inland navigation. Preparation of inland navigation development strategies in parallel with the river basin management plans of the WFD might provide the missing strategic basis for addressing conflicts between the interests of navigation and the environment. The report submitted to Ministers, CEMT/CM(2006)17, recommends that shipping and environmental protection authorities work together to produce strategies for the environmental protection and development of inland waterways at the river basin level.

Pan-European considerations

Pressure to increase profitability together with safety concerns lead industry to argue for large, deep channel dimensions to be provided wherever possible. At the same time industry generally recognises the need to protect the environment and the constraints this may impose on the development of navigation channels. Governments seek to promote the development of more pan-European inland shipping. This might be pursued through establishing a large standard channel specification for all international waterways but an alternative approach built up from river basin development strategies appears more likely to succeed than imposing uniform standards. Basin-wide strategies would need to take inter-basin traffic into account where river basins are interconnected but have the potential to make the different local, regional and pan-European dimensions more transparent.

SEA and multi-modal corridor assessment

The ideal strategic planning framework would include strategic environmental assessment (SEA) covering transport on the basis of multi-modal transport corridor analysis, along with non-transport demands on the waterway (for hydropower production, flood protection, irrigation, industrial use, drinking water abstraction and waste discharge). The relatively recent discipline of incorporating multi-modal corridor analysis in transport SEA is examined in detail in the report Assessment and Decision Making for Sustainable Transport published by ECMT in 2004. Transport ministers adopted a resolution and guidelines on good assessment in 2003,2 which were endorsed by environment ministers by an Act of the OECD Council.3 In the short term, however, a narrower focus on just navigation and environmental protection might be appropriate, as explained below in the next paragraph.

Conclusions

Priority action

Strategic framework for the Danube River

The report submitted to Ministers concludes that a strategic vision for protection and development of the Danube River is urgently required. Most of the waterway development projects entailing unresolved environmental issues are located in the Danube basin. Moreover, the planning and consultation procedures and the capacity for public administration and governance tend to become weaker as one travels down the Danube. Some of these weaknesses could be addressed by a structured dialogue between government, environment and industry stakeholders that aims to produce a consensus statement on inland waterway transport in the Danube basin. The focus of this work would be narrower than the ideal planning framework discussed above and concentrate solely on inland navigation (and not cover other uses of the river or other modes of transport). This would facilitate completion in good time to influence the River Basin Management Plan for the Danube, which has to be completed in 2009 to satisfy the requirements of the Water Framework Directive.

Bucharest 2006

The International Commission for Protection of the Danube River and the Danube Commission are in a good position to take a joint lead in the preparation of the consensus statement, under the guidance of a steering group consisting of high level representatives of the relevant stakeholders. The aim will be to complete the consensus statement by the end of 2007. Ministerial endorsement for this proposal will be sought at the Bucharest Pan European Inland Waterway Transport Conference in September 2006.

Other conclusions

Involvement of stakeholders and the public

The fundamental conclusion of the report submitted to Ministers is that prompt and successful decision making depends critically on the way the involvement of the public, environmental and industry stakeholders is organised, and especially on engaging with stakeholders early. This applies not only to the preparation of specific projects but also to the process of strategic planning.

Problem "ownership", not just consultation

Existing SEA and EIA procedures, at both EU and national level, require public consultation, but not necessarily public participation. The UN Aarhus Convention and associated EU directives deal with the right of the public to be informed, to have the opportunity to make comments and to have access to justice, rather than with public participation in the process of defining objectives, alternative solutions, boundary conditions and priorities. Moreover, SEA and EIA procedures generally require formal public consultation only after preparation of a project proposal or development plan. Experience and practice in several of the projects examined show that assessment procedures, as well as the probability of arriving at a workable solution within a reasonable time, greatly benefit from early involvement of project beneficiaries and environmental stakeholders, who thus take on "ownership" of the problems involved and feel accountable for and committed to finding integrated solutions. This requires a highly participative and integrated approach: an open planning process where all stakeholders (government agencies, private sector, NGOs, public, etc.), from the early stages of preparation onwards, play an active role and jointly develop commitment to the project.

Dredging contaminated sediments

Finally, the report singles out dredging operations for particular attention. Often waterway and port authorities inherit problems associated with polluted sediments when they were not responsible for the pollution that caused the contamination. A legal and procedural framework must be developed for ensuring that channel excavation for waterway development and maintenance dredging can be planned and executed while (a) respecting the strict national and European regulations on polluted sediments and (b) applying the polluter pays principle. This will take time. In the meantime it is essential that inland navigation is not burdened with the excess costs of handing polluted sediments, compared to the cost of dredging uncontaminated sediments. The International Commission for the Protection of the Rhine began work in 2005 on a strategy to manage sediments for the Rhine and its tributaries. The results should serve as a basis for developing a Europe-wide strategy on managing polluted sediments.

NOTES

1. By-passing meanders, straightening of main channels, raising or lowering of water levels etc..

2. Resolution 2003/1 on Assessment and Decision Making for Sustainable Transport.

3. Recommendation of the Council on Assessment and Decision-Making for Integrated Transport and Environment Policy, 21 April 2004 - C(2004)80.

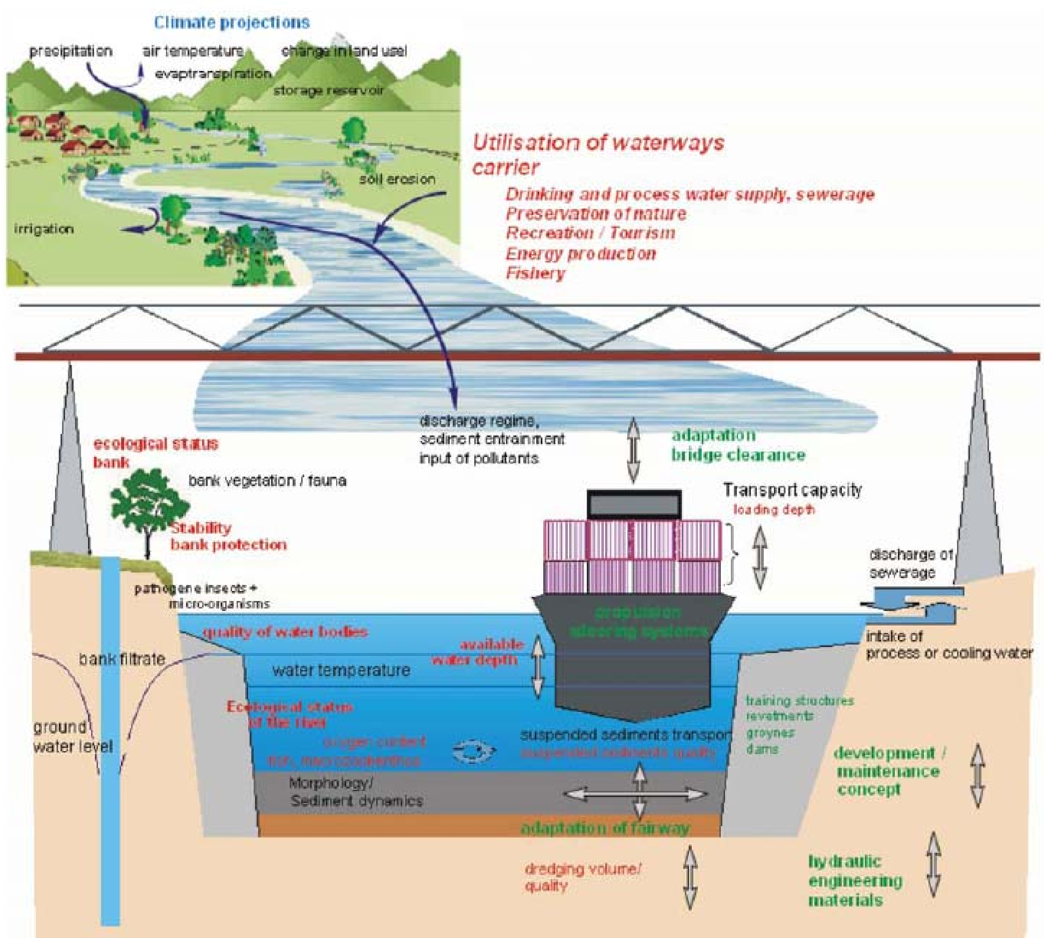
APPENDIX 2

Impacts of climate change

(from PIANC Report on climate change and navigation)

The main goal of EnviCom Task Group 3 *Climate Change and Navigation* was to discuss the climate change related issues for the navigation sector and how to deal with the above-mentioned problems and various project scenarios. Potential adaptation and mitigation responses were also identified.

Climate change impacts inland navigation primarily through ice conditions, icing, extreme hydrological conditions, river morphology, wind conditions etc. Links between drivers of change and potential impacts on inland navigation are depicted in the following figure.



Potential impacts on navigation - primarily in terms of water depth and velocity, resulting in changes in sedimentation and presence and absence of ice – are listed in the following table

Drivers	Impacts	Rivers, channels, canals, lakes	Locks, dams, and infrastructure	Operational control	Vessels
Water supply: increased precipitation Extreme conditions: more extreme floods	Increased water level and velocity	x	x	x	x
	Changes in sedimentation processes (bank failure, local scour, locations of aggradation and degradation)	x	x	x	
	Manoeuvrability		x		x
	Increased loads on structures		x		
	Decreased development land area available		x		
	Reduced regularity of the port		x	x	
	Reduced capacity of natural systems to recover	x			
Water supply: decreased precipitation Extreme conditions: more extreme droughts	Decreased water level and velocity	x	x	x	x
	Reduced regularity of the port		x	x	
	Changes in sedimentation processes (locations of aggradation and degradation)	x	x	x	
	Reduced capacity of natural systems to recover	x			
Water supply: changes in form and quantity of seasonal precipitation	Change in timing of seasonal high water and seasonal low water	x	x	x	x
	Changes in sedimentation processes (locations of aggradation and degradation)	x	x	x	x
Water temperature increases	Ecosystem impacts affecting habitat	x		x	
	Oxygen depletion	x		x	
	Reduced capacity of natural systems to recover	x			
River morphology	Changes in sedimentation processes (locations of aggradation and degradation)	x	x	x	x
	Ecosystem impacts affecting habitat and lifecycle				
	Reduced capacity of natural systems to recover	x			
Changes in ice cover	Shorter duration of river ice	x	x	x	x
	Changes in locations of ice jams	x	x	x	

If navigation conditions are altered over a longer periods of time (low water levels for instance) adaptation of the fleet and new vessels of different design seem to be inevitable. The following table summarizes some possible responses which, however, require additional investments and/or cause higher operational costs.

Area of intervention	Response (measures)	Additional information
Waterway design and maintenance	Creation of water storage facilities	(Upstream) reservoirs needed for flood mitigation could also be used to improve navigation
	Deepening of channels instead of widening	
Waterway operation	Managing water flow	Store water in times of high water flow, release water in times of low flow
	Improving forecast of water level	Better information, further ahead, could optimise the use of vessel capacity for given conditions, and reduce uncertainty margins
	Improved queuing procedures	Decision support systems and automation of queuing could help to overcome capacity restrictions of waterway infrastructure
	Implementation of River Information Services (RIS)	RIS in general support safe and efficient navigation
	Providing up-to-date electronic charts of fairway with water depth information	Better information to optimise use of vessels in given conditions, and reduce uncertainty margins
Transport management	Chartering of additional vessels	
	Increasing daily operation times of vessels	
	Cooperation with other modes of transport	Contractual arrangements with road and rail transport can be made for times of reduced navigability
	Increased storage of goods	
Vessel operation	Employing sophisticated Inland ECDIS (Electronic chart display and information system)	Provision of all necessary and always up-to-date information, better to utilize given navigation possibilities
Vessel design	Reduction of weight	Using alternative design or materials, installing lighter equipment
	Increasing width	Wider vessels need less draught

APPENDIX 3

Wave Wash Produced by High Speed Craft [2nd CPBS, 2010]

Fast vessels produce wave wash that is different than that of conventional ships and natural waves, having long periods and significant energy. The amplitude of the leading wave produced by high speed craft is not so large (when compared to storm waves, for instance) but it does have a relatively long wave period. When these waves reach (get into) shallow water their height increases rapidly, often causing large and damaging surges on the beaches. They also arrive unexpectedly, often after the high speed craft has passed away. Consequently, wash restrictions were implemented on several sensitive high speed craft routes. During the last 20-years of evolution, wash restrictions were first based on speed limits, then wave wash heights, and ultimately by the limitation of energy produced by wash at certain distance from the vessel's track. According to the latest findings both wash height and energy are important; see for instance Cox (2000) and Doyle et al. (2001).

Concerning wash in the sheltered waters, it is only a vessel's divergent waves which are relevant. A visual indicator of wave wash size is usually its height only; however the wave period seems to be the critical factor regarding damage.

Deep water

As mentioned above, wave wash restrictions are now based on the energy in the wave train. By using this approach the wave height and period are taken into consideration. For example, the State of Washington restrict wave wash energy, E, to values of less than 2450 J/m at a distance of 300 m off the vessel's track, or 2825 J/m at a distance of 200 m off the vessel's track.

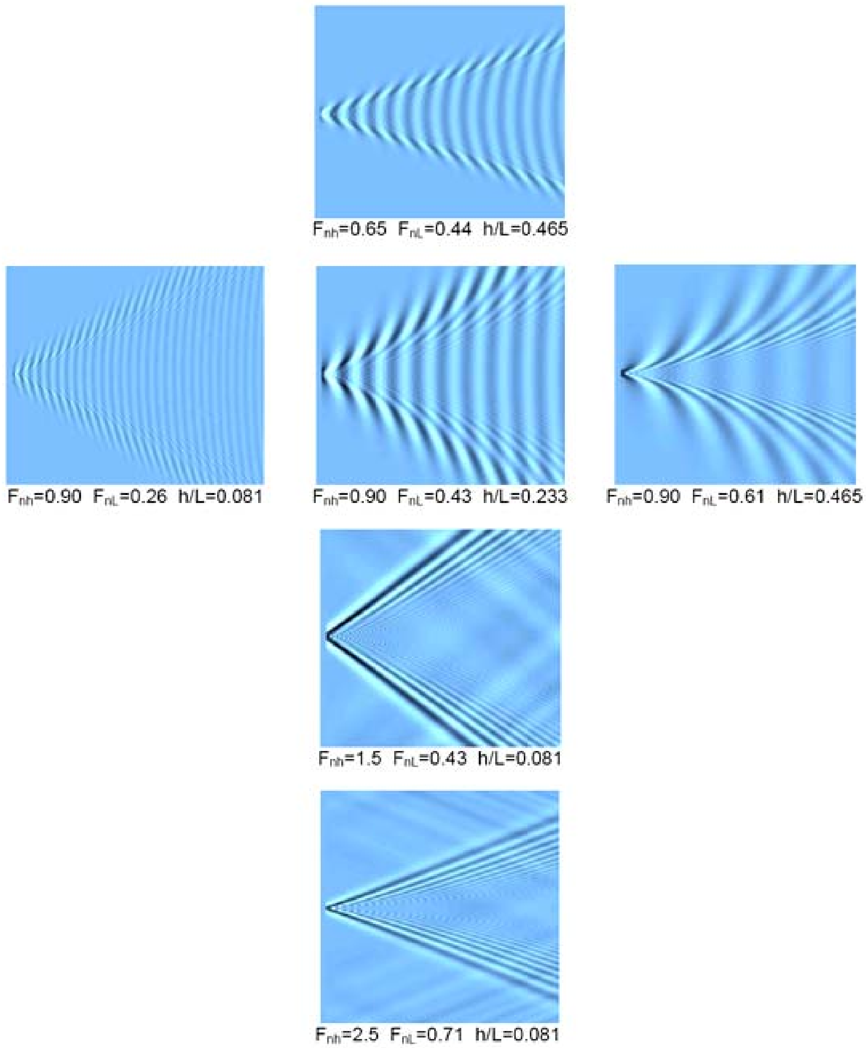
The distances from the vessel are included in the requirements because wave height diminishes as the lateral distance from the sailing line increase. The decay rate in far-field (distances beyond two waterline lengths) may be obtained from the relation $1/x^{0.33}$, where x is distance perpendicular to ship track. It should be noted, however, that the wave period is nearly constant as distance x changes.

The calculations of wave wake energy per linear length of wave front is given by the following equation, in which the period, T, is associated with the maximum wave height.

$$E = (\rho g^2 H^2 T^2)/16\pi = 1960 H^2 T^2 \ \text{J/m} .$$

Shallow water

The characterization of shallow water waves is more complicated because wave period also varies with distance from the sailing line. Longer and faster waves travel on the outside of wash and have a larger Kelvin angle than the shorter and slower waves. When the waves are in very shallow water and the supercritical region, the first wave in the group is usually the highest. However, as depth increases, the second or third wave typically becomes the highest. Figure below[1] depicts wave patterns in shallow water in sub-critical, critical and super-critical region.



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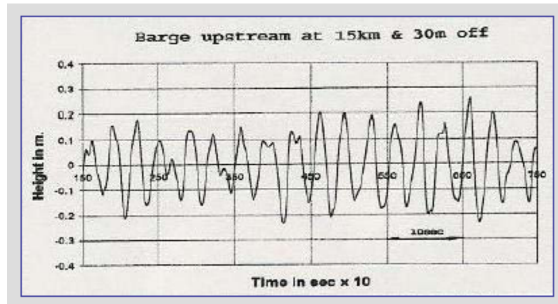
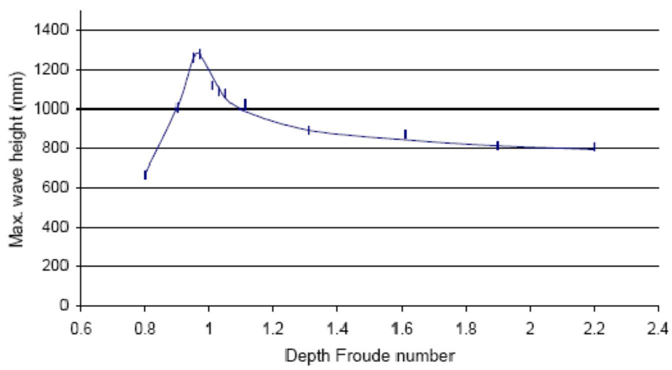
[1] Combined influence of length Froude number and depth Froude number on wave height is depicted (Michlet Software, © Leo Lazauskas was employed to calculate surface wave patterns for various length Froude numbers and depth Froude numbers). The images in the center vertical column are for a constant length Froude number $F_{nL} \approx 0.43$ (except the last image), while depth Froude number increases from 0.65 to 2.5. On the other hand, the images in the center horizontal row have a constant depth Froude number (F_{nh}=0.90), while length Froude number increase from 0.26 to 0.61. The last image depicts waves for the supercritical speed, i.e. F_{nL}> 0.7. The progression from the top to bottom of the vertical figures illustrates the wave pattern changes associated with transitioning from the subcritical regime to the supercritical regime. Relative to this, the horizontal figures, all evaluated for the same depth Froude number, depict somewhat different wave patterns and heights with the different length Froude numbers. The middle figure has the maximum wave height as F_{nh}=0.9 and $F_{nL} \approx 0.4$.

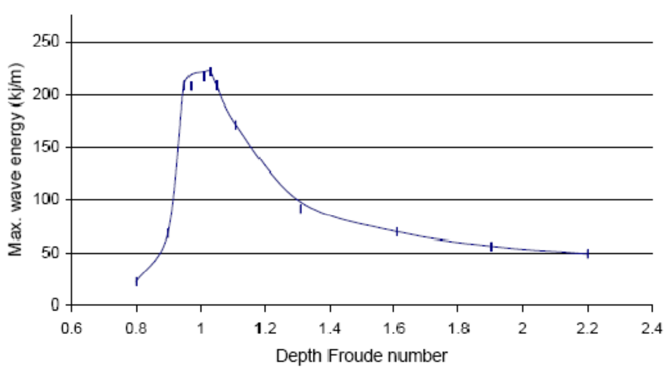
The appropriate measure of wave wash in shallow water seems to be both the wave height and wave energy, which can be obtained from the wave wash trace (for instance, typical Rhine barge wash (sub-critical speed) at 30 m off vessel track, having height 0.47 m and period 3 sec, hence E=1030 J/s at 200 m is depicted below).



Source: Lewthwaite 2006

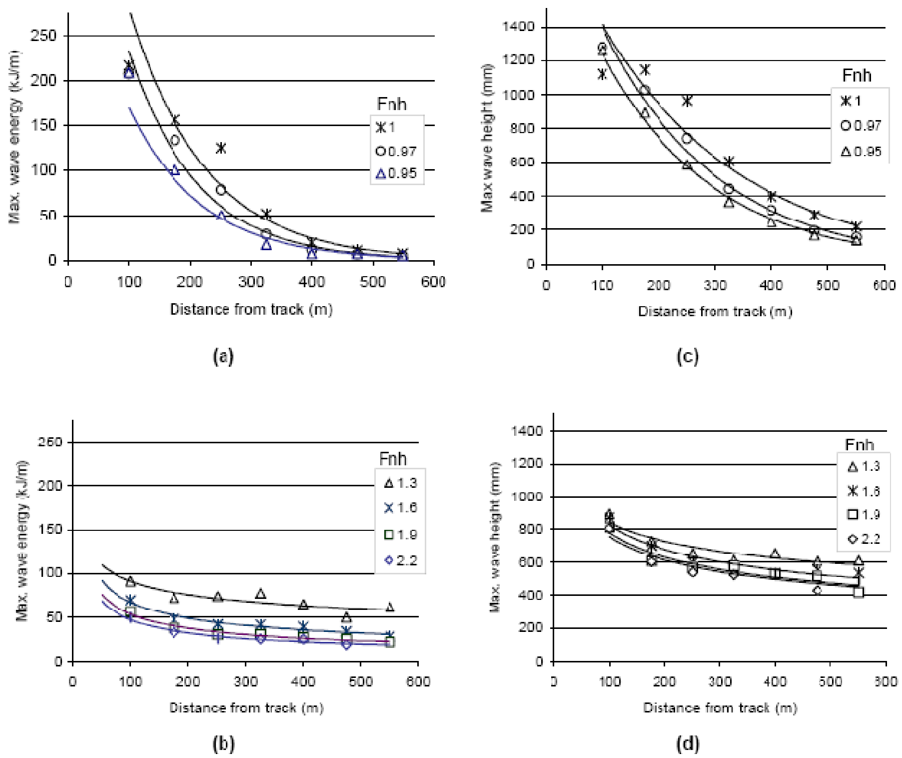
As expected, the largest waves occur around F_{nh}=1. Variation of wave height and energy with depth Froude number recorded at x≈L are shown below.





Source: Doyle, 2001

Most of the energy is contained in a single long-period wave with small decay energy dispersion at a distance. The decay rate in shallow water is smaller than in deep water and is a function of h/L ratio. The decay ratio at critical speeds is different than that in supercritical region, as shown below. This is a contributing factor to unexpectedly large waves in shallow water at a larger distance from a vessel's track. If ratio h/L>0.5, the waves are more or less the same as in deep water.



Source: Doyle, 2001

Low Wash Hulls

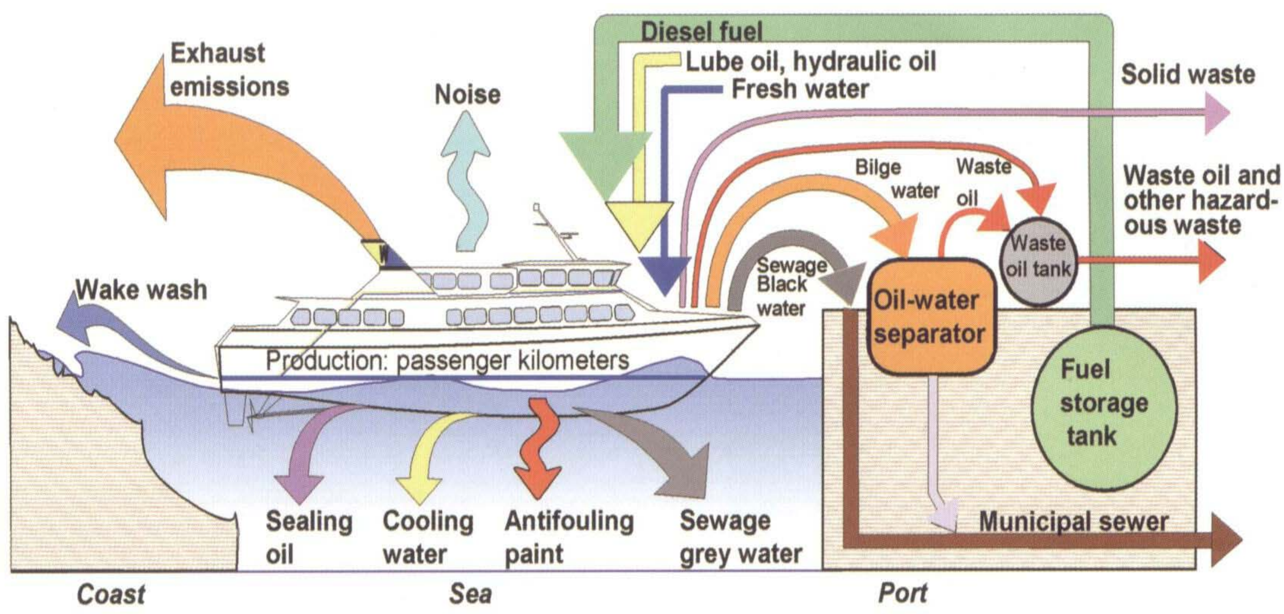
Naval architects are nowadays trying to identify a low wave wash hull form characteristics. Generally, for a low wash a) the speeds corresponding to F_{nL}=0.35-0.65 should be avoided, and b) displacement should be as low as possible while length should be as large as possible. According to Cox (2000) there is no sufficient evidence for claims that catamaran, multi-hull vessel, or any other form is significantly better than monohulls (provided comparison is made between competent designs). According to PIANC 2003, high speed craft wave wash cannot be reduced just by optimizing the hull form and various design ratios since wave period generally increases with speed and doesn't decay quickly, which is important for navigation particularly in shallow water.

APPENDIX 4

Possible Ship Pollutants

Prevention of pollution by inland vessels is generally regulated by various international and national rules (see UN ECE Resolution No. 21, for instance). Of particular interest are ADN Rules *(International Carriage of Dangerous Goods by Inland Waterways)* which represent a set of regulations which play an important role in controlling water pollution by inland navigation vessels.

As a consequence of above-mentioned inland navigation vessels have to be equipped with appropriate technical means for collection, retention on board and transfer into reception facilities (shore based and floating) of waste generated on board. Possible ship pollutants are indicated in the following Figure.



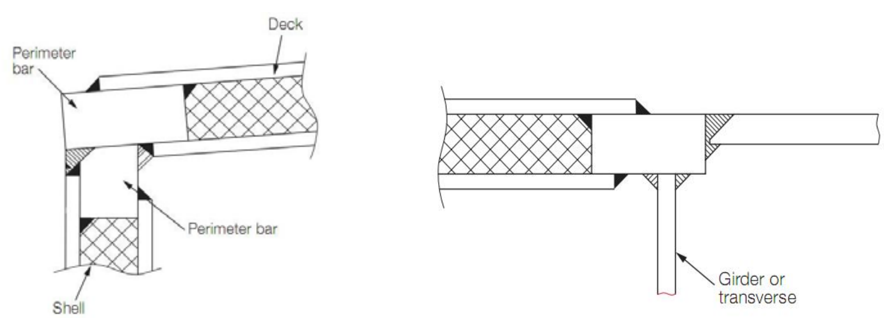
Source: Highlights 3/2003 - A newsletter published by SSPA, Sweden

APPENDIX 5

Application of SPS to Danube Barge Hull Structure

Sandwich Plate or Panel System (SPS) consists of two plates with welded perimeter bars and with an elastomer injected between to form a solid unit. In 2006 LR revealed *Provisional Rules for the Application of Sandwich Panel Construction to Ship Structure.* The **Rules** cover construction procedures, scantling determination for primary supporting structures, framing arrangements and methods of scantling determination for steel sandwich panels. The *Rules* are in general applicable to mono-hull ships of normal forms, speed and proportions. As usually, application of SPS in any area that is not specified in the *Rules,* requires special consideration by LR.

The overall philosophy of the **Rules** is to ensure that designs utilising steel sandwich construction are equivalent in strength and safety to conventional steel construction. The thickness of the top and bottom plate and core of the SPS is determined on basis of the scantlings given for the equivalent ordinary steel construction. The assumed scantlings of SPS construction are checked for strength by formula given in the *Rules.* If the strength is not satisfied, the chosen thickness has to be increased. The process is iterative. Welding is conducted via the perimeter bar, see connection details below.



The purpose of the investigation was to validate whether application of SPS construction to a Danube barge can lead to significant weight reduction (40% or so as reported, for instance, by Jastrzebski 1993). A typical general cargo Danube barge of 77x11x2.8 m is chosen for this comparison. A conventional steel structure was evaluated according to LR *Rules and Regulations for the Classification of Inland Waterways Ships* (for general cargo, bulk carrier and container ship type), while *Provisional Rules* were used for SPS structures.

Weight comparison was made between following concepts:

a) An existing, conventionally-built (mixed framed) steel barge, built 30 years ago according to *Yugoslav Register of Shipping Rules,*

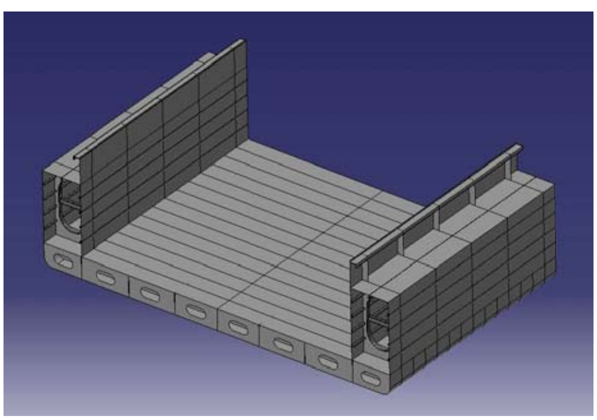
and calculated (according to LR) conventional steel barge with two types of structures

b) mixed framing system
c) longitudinal framing system,

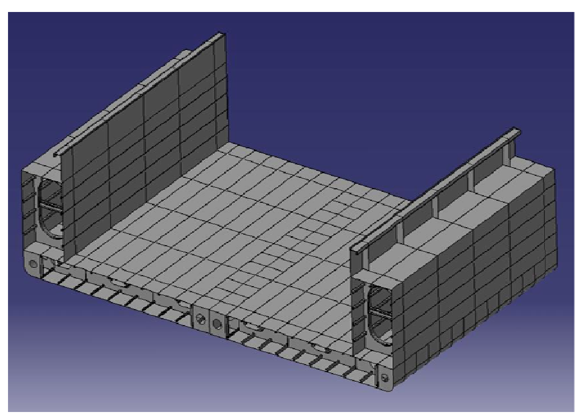
as well as innovative (calculated according to the *Provisional Rules)*

d) SPS structure.

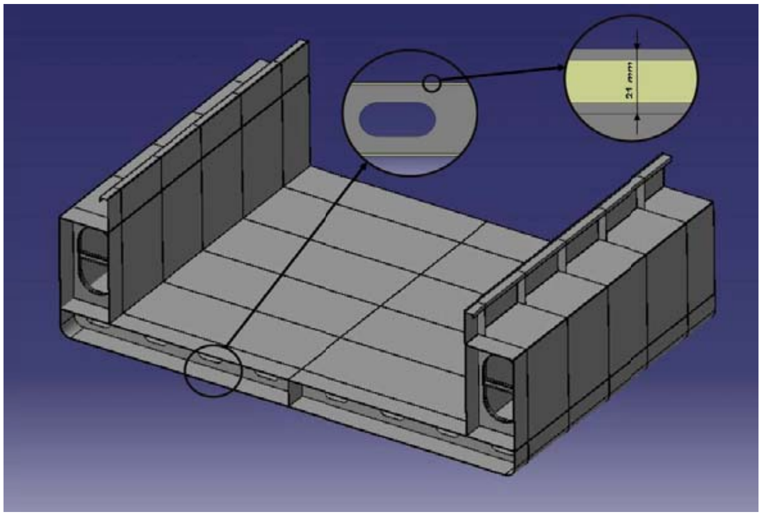
A longitudinal framing system is the type of ship structure in which all secondary structure stiffeners are set up longitudinally, while in a transversally framing system all secondary structure stiffeners are positioned transversally. A mixed framing system denotes here double bottom to be transversally framed, while the double side and deck are longitudinally framed. The existing barge is built with mixed framing system, which is nowadays typically applied for inland barge structures. Considering the local strength requirements, stern and bow structures are assumed to be conventionally built and therefore remain the same in all cases. Figures below represent part of the midship section of the barges considered.



Mixed framed
(cases: a) existing, and b) calculated)

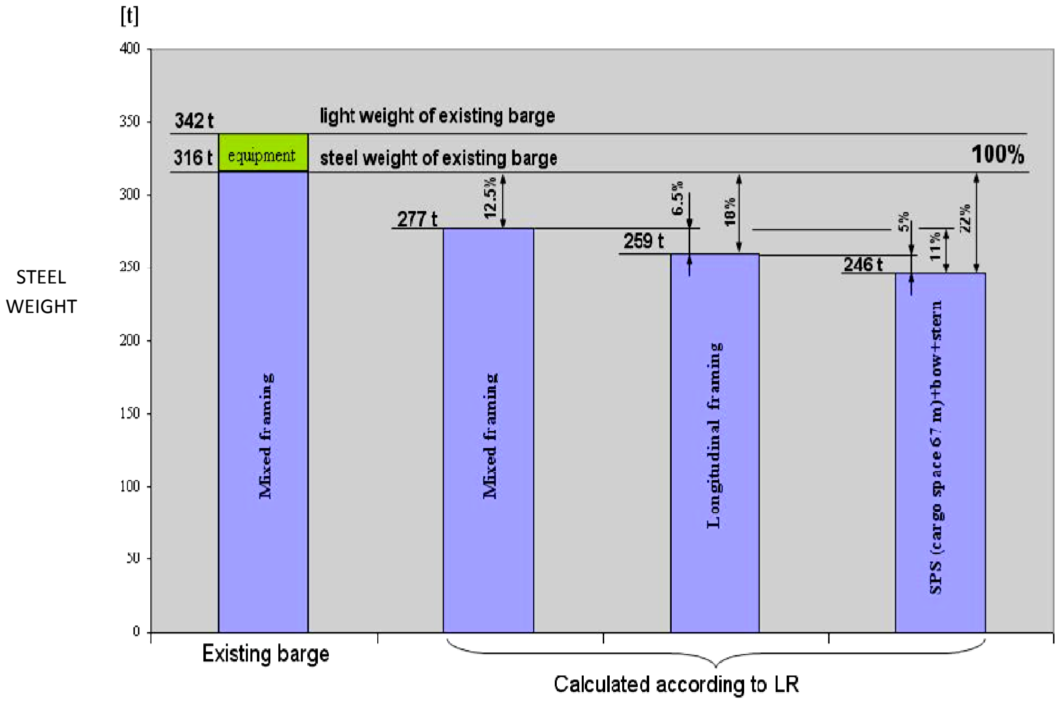


Longitudinally built barge (case: c) calculated)



SPS construction (case d) calculated)

Weight comparison for general cargo Danube barge (77x11x2.8 m) for all four considered cases is shown below.



Comment:

- Complete steel weight is shown consisting of middle body of 67 m and bow & stern of 10 m.
- Total light weight of particular JRB barge is 342 t (steel weight 316 t and equipment 26 t).
- Weight of bow & stern is assumed to be the same (53 t) in all cases.

Concluding remarks

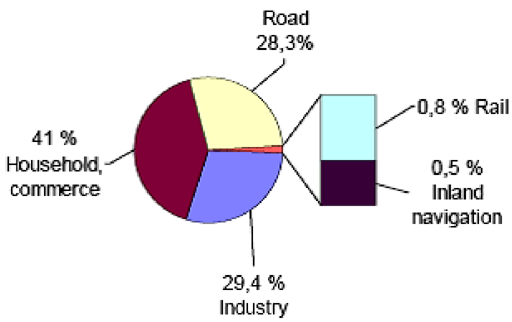
Due to the various exploitation reasons the hull structure scantlings of the calculated barges are often increased, allowing them to meet strength requirements over a prolonged period (more than 50 years). Consequently, the existing barge is heavier by around 12.5% than an equivalently framed calculated barge. If longitudinal framing would be used, this difference would be 18%, although a conventional steel structure was assumed for both cases. The innovative SPS structure would be lighter by 22%, 11% and 5% respectively. Summarising, the innovative SPS barge can be lighter by only up to 10% than a conventional (calculated) barge.

Nevertheless, it seems that weight savings should first be examined within the conventional steel construction approach, and afterwards the innovative approaches, like SPS, could be examined.

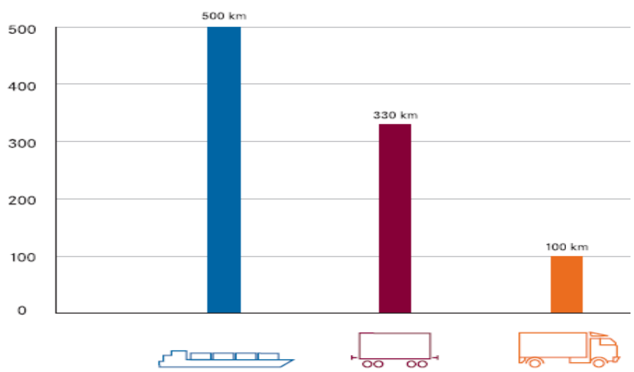
Note that container and bulk-cargo barges (that were also analysed) are heavier by around 10% than the general cargo barges and that a savings due to application of SPS construction would be smaller - around 2 to 5% only.

APPENDIX 6

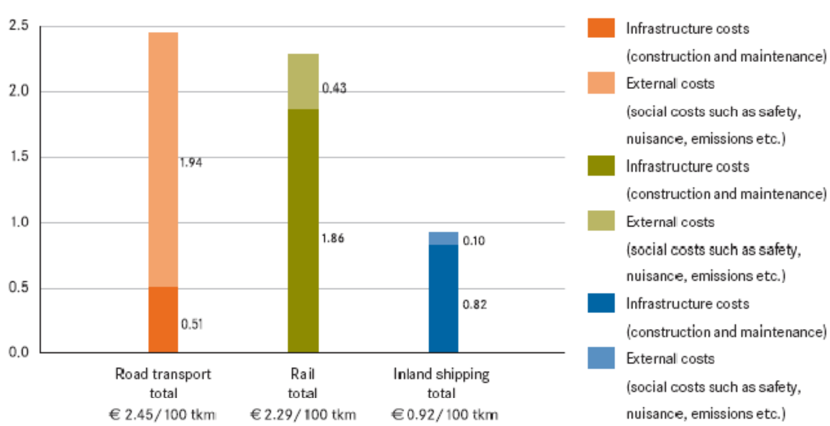
Statistics on Inland Waterway Transport and Danube Transport



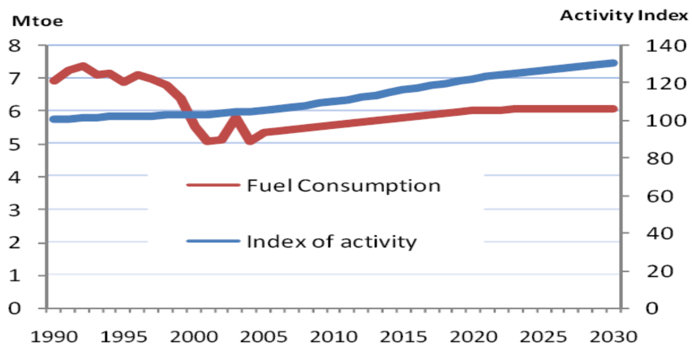
Within total traffic energy consumption Road+Rail+IWT, IWT's share is only about 1.5 % (Source: EEA)



Transport distance per mode with fuel consumption of 5 lit/ton (Source: BVB)



External cost of goods transport (Source: BVB)



Energy consumption in inland navigation (Source: EC DG for energy & transport)

CONGESTION - IWT has no restrictions on freight growth (allowable increase on the Rhine and Danube are 4 and 10 times, respectively). Furthermore, it is the only mode which can relieve congested roads and railway.

Recent USA statistics (from *Maritime Today E-news,* June 17th 2009)

"A Modal Comparison of Freight Transportation Effects on the General Public"
www.nationalwaterwaysfoundation.org

The research team focused on Carbon Dioxide (CO2) emissions, which are currently the focus of the public policy debate on Green House Gasses. Using EPA parameters, the team calculated how much CO2 is emitted per ton mile for each mode. Emissions per ton mile are those emissions experienced in moving one ton of cargo one mile. The team determined that the emissions of CO2 per gallon of fuel burned are roughly the same for each mode, so the comparison focused on how much cargo gets moved for that gallon of fuel. They determined that compared to inland barge transportation, rail transport generates 39% more CO2 and trucking generates 371% more CO2.

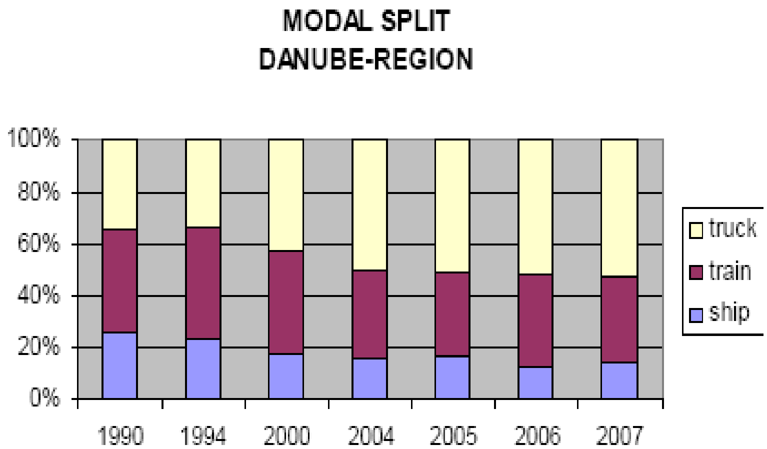
Trucks can only produce 155 ton-miles of cargo movement per gallon of fuel and can deliver only 13,964 ton-miles of cargo movement for each ton of CO2 produced.

Railroads produce 413 ton-miles of cargo movement per gallon of fuel, allowing them to 37,207.2 tons-miles of cargo movement per ton of CO2 produced.

Inland towboats move the most cargo per gallon of fuel -- 576 ton-miles per gallon -- and thus produce the least amount of CO2 emissions per ton mile, delivering some 51,891 ton miles of cargo movement for each ton of CO2 emitted.

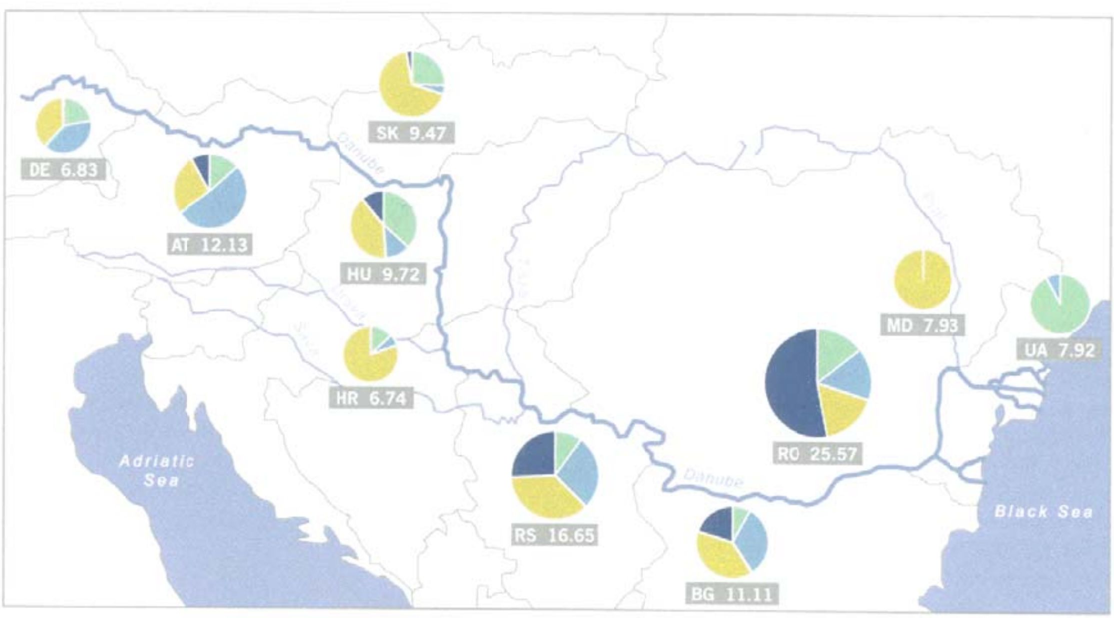
To put these numbers in perspective, the research team calculated that if all the cargo that moved by barge in 2005, the year of the study, were instead moved by rail, it would have resulted in an additional 2.1 million tons of CO2 in the atmosphere. If that same cargo had moved by truck, it would have generated an additional 14.2 million tons.

Regarding the same subject, see also Crist (2009) paper on Greenhouse Gas Emissions (OECD publ.).



Market share development of cargo transport on the Danube
(Source: Mierka Donauhafen)

TOTAL FREIGH TRANSPORT ON THE DANUBE 2007
In million tons/year



MILLION TONS	DE	AT	SK	HU	HR	RS	BG	RO	MD	UA
Export	1.53	1.63	2.43	3.57	0.89	1.69	0.90	3.71	0.00	7.32
Import	2.70	6.29	0.42	1.20	0.44	4.56	3.66	4.03	0.01	0.60
Transit	2.57	3.24	6.38	3.88	5.41	6.12	4.32	4.32	7.92	0.00
Domestic	0.03	0.97	0.24	1.07	0.00	4.28	2.23	13.51	0.00	0.00
Total	**6.83**	**12.13**	**9.47**	**9.72**	**6.74**	**16.65**	**11.11**	**25.57**	**7.93**	**7.92**

Source: Danube Navigation in Austria, Annual Report 2008, *via donau*

Danube fleet (2003) – Source: Prospects of the Development…, *via donau*

Ship type	Number	Capacity (1000 t)	Average age (years)
Motor cargo vessel	104 (6206)	160 (6158)	29 (50)
Dry cargo barges	1796 (2522)	2842 (3348)	24 (29)
Tankers	8 (1390)	10 (1771)	29 (36)
Tank barges	192 (147)	258 (215)	41 (34)
Pushboats	283 (675)	-	24 (49)
TOTAL	2631 (10940)	3256 (11492)	26 (44)

Comment: In the parentheses given are data for the Rhine vessels. Only vessels that are appropriate for the international trade are contained. Only vessels larger than 1000 t are contained for the Danube statistics. Pushboats with engines larger than 750 kW are contained for the Danube statistics.

Estimated fleet demand for the Danube in 2015 (number of vessels)

Source: Prospects of the Development…, *via donau*

Ship type	Year 2003	Total demand	Additional Demand
Motor cargo vessel	104	293-428	189-324
Dry cargo barges	1796	769-1117	0
Tankers	8	38-55	30-47
Tank barges	192	112-162	0
Push boats	283	169-246	0
TOTAL	2631	1381-2008	219-371

Comment: For details see the source document. Total demand and additional demand are given “from-to” as the number depends on actions undertaken for improving the navigation. Additional demand is construction of new vessels due to fleet modernization.

APPENDIX 7

Recent IMO Activities

It should be mentioned that **IMO's Marine Environment Protection Committee (MEPC)** is, amongst others, developing measures to enhance energy efficiency in international shipping and thereby reduce greenhouse gas emissions. These are technical and operational measures as well as possible market-based instruments. Consequently, the following was introduced:

Energy Efficiency Design Index (EEDI) for new ships, on the basis of experience gained through its trial application over the past six months. The EEDI is meant to stimulate innovation and technical development of all the elements influencing the energy efficiency of a ship, thus making it possible to design and build intrinsically energy efficient ships of the future.

Energy Efficiency Operational Index (EEOI), which enables operators to measure the fuel efficiency of an existing ship and, therefore, to gage the effectiveness of any measures adopted to reduce energy consumption. The EEOI has been applied by Member States and the shipping industry, on a trial basis and since 2005, to hundreds of ships in operation; it provides a figure, expressed in grams of CO2 per tonne mile, for the efficiency of a specific ship, enabling comparison of its energy or fuel efficiency to similar ships.

Ship Energy Management Plan (SEMP) incorporates guidance on best practices, which include improved voyage planning, speed and power optimization, optimized ship handling, improved fleet management and cargo handling, as well as energy management for individual ships.

The above mentioned is a successor instrument to the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) and concerns seagoing ships, but sooner or later similar measures will have to be applied to inland ships too. In the context of this study, EEDI, EEOI and SEMP are related to subjects presented in Section 7.

MEPC is currently developing a **Convention on ship recycling regulations** for international shipping and for recycling activities. The new convention (expected to enter into force in 2013) will provide regulations for the design, construction, operation and preparation of ships so as to facilitate safe and environmentally sound recycling, without compromising the safety and operational efficiency of ships; the operation of ship recycling facilities in a safe and environmentally sound manner; and the establishment of an appropriate enforcement mechanism for ship recycling, incorporating certification and reporting requirements. Consequently, every new ship will have to enter service with a certified Inventory of Hazardous Materials (IHM) and the shipyard will be responsible for preparing it.