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NEW PROGRESS IN DESIGNING INLAND CARGO VESSELS. A WINNER FOR FUEL-EFFICIENCY

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SUMMARY

Ongoing developments, supported by experiments in the field, in the hydrodynamic segment of inland cargo vessels over the past ten years, have led to a fundamentally better economical use of the propulsive energy.

The herewith possible limitation of installed power has a side effect into the reduction of exhaust gas quantities. In the evaluation of transport relations to be implemented, the environment protective impact will get a significant higher order in the near future than at present. This could be expressed in an environment correlated figure, which would indicate **the exhaust gas quantity per ton kilometre.**

Progress in the design of inland cargo vessels has fully taken this development into account, same as with a further increase in economic efficiency

1. INTRODUCTION

Although the share of Traffic- and Transport means in the total consumption of primary energy on earth is relatively small, its effect on the environment is considerable.

It should be absolutely imperative to reduce the harmful content in exhaust gas from fossil fuels as much as possible, and of course the **amount** of exhaust gas itself.

Inland navigation uses inland transport routes and competes with land transport means. In this context it is physically capable and thereto predestined to transport huge amounts of cargo with relative small energy consumption.

Both for reasons of environment protection as well as for economic reasons it will be significant to reduce the energy consumption further till the lowest possible minimum.

2. INLAND NAVIGATION IN THE CONTEXT OF THE PRINCIPAL EUROPEAN MEANS OF TRANSPORT

Favoured by the numerous and partially very well expanded waterways, Inland Navigation within the EEC possesses a noteworthy share in the total transport volume. For cargo transport by means TRUCK AND LORRY, RAILROAD AND INLAND NAVIGATION, the modal split is represented in the following tables:

TABLE 1
Inner BRD transport [1] , [3]

mode	transported amount t/yr [%]	transport performance tkm/yr [%]
LORRY & TRUCK	42	48
RAILROAD	32	28
INLAND NAVIGATION	26	24

TABLE 2
Border passing transport within the EEC [2]

mode	transported amount t/yr [%]	transport performance tkm/yr [%]
LORRY & TRUCK	43	?
RAILROAD	13	?
INLAND NAVIGATION	39	?

note: figures valid for 1987/88

According to the BRD Traffic Route Plan (1985), the Inland Navigation in the BRD will maintain, if not increase, their transport performance (in tkm/yr), till the year 2000 [3].

The Steering Committee PROGNOS/BVU, Basel predicts for the year 2015, compared to 1985, a Cargo Transport increase (in t/yr) by inland vessel of 21% (ref.[4]).

We distinguish within the cargo fleet of the Inland Shipping means of transport, the following **transport systems:**

- **single motor cargo vessel**
- **barge pushing motor cargo vessel**
- **pushboat/ pushbarge combinations**

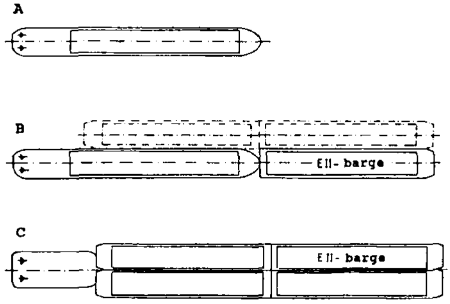
Figure 1 shows dimensions and payload capacities of modern vessels and vessel combinations as presently being deployed on the river Rhine and partially its on tributaries.

The trends of the last decennia indicates an increase of transport capacity and/or transport volume for the single motor cargo vessels, respectively the motorvessel combinations.
A single hold per vessel became normal.

In the context of present day and future research and development the preponderant objectives are:

- **hydrodynamic and propulsive optimization**
- **cargo transfer friendly design**
- **traffic safe operation**
- **environment friendly deployment**

A SINGLE MOTOR CARGO VESSEL
B PUSHING MOTOR CARGO VESSEL - PUSHED BARGE COMBINATION
C PUSHBOAT - PUSHED BARGE COMBINATION



	PROBABLE LIMITS L×B [m]	payload capacity [t]
A	11,0 × 11,40	3600
B	19,0 × 22,80	11700
	19,0 × 11,40	6300
C, 4 barges	190 × 22,80	10800
C, 6 barges	270 × 22,80	16200

fig. 1. Modern vessel and vessel combinations plying the river Rhine

3. REDUCTION OF THE SPECIFIC PROPULSIVE POWER, KEY TO ECONOMIC- AND ENVIRONMENT AWARE VESSEL OPERATION

The economic use of energy in Inland Navigation is -since the 'energy crisis' of the seventies- characterized by in-depth efforts to maximize the **TRANSPORT EFFICIENCY.**

TRANSPORT EFFICIENCY (GENERAL)

$$G_{TL} = \frac{L \cdot V_G}{P_B} = \frac{V_G}{P_B / L} \quad \left[\frac{tkm}{kWh}\right]$$

L = payload quantity [t]
V_G = velocity over ground [km/h]
P_B = installed engine power [kW]

SPECIFIC VALUES FOR COMPARISON OF INLAND VESSELS

$$G_{T\forall} = \frac{V_G}{P_B / \forall} \quad \left[\frac{m^3 km}{kWh}\right] ; \quad \forall = \text{displacement} \quad [m^3]$$

$P_D / \forall$ [kW/m³] = displacement related propulsive power

fig. 2. Transport efficiency formulae

The general formula (top) can be suitably transformed into a relation between ships velocity (V) and the payload related propulsive power (P_B /L) as shown at the bottom of figure 2.

With vessels, in particular when sailing in shallow waters, an increase of velocity tends in general to a reduction of the **transport efficiency** (G_{TL}), because of the increase of the required propulsive energy to the third, or much higher, power of the velocity.

This phenomenon of a decline in the payload related propulsive power (P_B/L) at certain speed and shoaling water, must get the full attention of R & D in the hydrodynamic segment of Inland Navigation.

As such this recommendation is confirmed by a recent publication titled "Energy-saving Potential of the Inland Navigation Sector in the Netherlands" [ref.5, January 1990].

Starting from an already optimized ratio **payload to displacement** which is subject to separate efforts for improvement in the area of hull construction and strength, and taking as a constant value the **mechanical engine/propeller efficiency** then the appropriate alternative for research comes forward being: the **displacement related, specific propeller power** or in formula: P_D/V **[kW/m3]**

The hydrodynamic researcher has consequently the obligation to find means to move a maximum of displacement with a minimum of power, at a preselected speed. (ref. [6],[7]).

In a comparison the boundary conditions must be corresponding be , for obvious reasons. They are in this case:

- **the mean WATERDEPTH (h)**
  and
- **the vessels DRAUGHT (T)**

To these underlying conditions the following factors of influence apply:

- **the vessels total resistance**
- **type, size and arrangement of propulsion and steering means**
- **interaction between hull and steering- and propulsion means.**

Increasingly the interactions around the vessel itself, but also between vessel and waterway are being considered and appreciated as decisive for an energy saving-, and therewith an economically favourable vessel design.

The design criteria and recommendations which are valid for deep water navigation, can change drastically when shallow water navigation comes into focus.

A widely used parameter of hullform is the block coefficient C_B, which for inland vessels with their often more than 60% parallel midship length, for that matter cannot be applied reasonably any more. The shape of the vessels extremities alone is already of unproportional greater influence than the rectangular midship section.

For such vessels separate elaboration of fore- and aftship sections is obtained through individual block coefficients.

The hull shaping itself -the three dimensional composition of fore and aftship section- for inland vessels, which are sailing on continuously changing waterdepths, is up to nowadays mainly determined by the experience and feeling of the Designer.

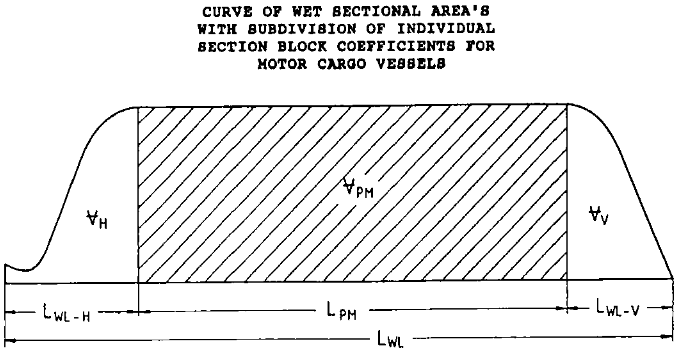


fig. 3. Subdivision of total block coefficient c_B

Apparently the CAM (Computer Aided **Manufacturing)** process has a lead on the CAD (Computer Aided **Design)** process, and probably will continue to do so for some time to come.

As an intermediate step until useful CAD methods become available, the introduction of EAD (Experimentally Aided Design) has proven its reliability.

This is where one encounters the principal area of interest for the Shipbuilding Research Centres, notably more so because of the possibility to subdivide the research on the various factors of influence.

Starting from a basic design as supplied by the Client, the optimization as pursued can be obtained in various stepsof model development, or at least be approximated. The above mentioned interactions should be identified and in an ideal case, be reconciled to mutual profit.

Of particular advantage is that the method of minimizing the specific power requirements, when executed in this way, is of almost equal significance as minimizing the fuel consumption and therewith the amount of exhaust gases.

Serving equally both the aspects of Economy and Environment will thus become accounted for.

4. PRACTICAL RESULTS

example 1
The improvement of the bowform of a pushbarge

The original bowform of the standard barge type EUROPE I was characterized by its, under 30 degrees rising, pontoon bow with cut edges as an extension from the bilges.

This model was not satisfying on shallow water, since the bowform induced an excessive flow around the foremost bottom section. Such a flow increases the frictional resistance, creates a bowtrim and increases the dynamic sinking. The latter causes amongst others an increase of the so-called residuary resistance

In several small- and two bigger steps the Duisburg Shipbuilding Research centre succeeded between 1980 and 1983 to create the so-called **wedge frame bowform.** [8],[9]

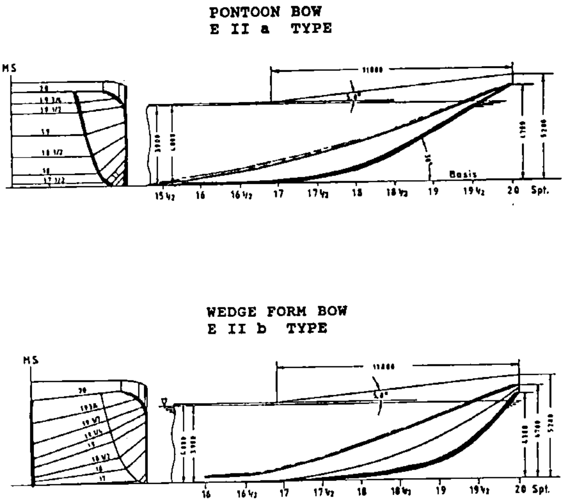


fig. 4. Improvement of the push barge bowform

A particular problem was the fact that the improvement not always would come to effect when applied in pushed convoys of two or more tiers.

Figure 5 and 5a show the advantages of the final bowform model E IIb, compared to the so far applied bowform E IIa of a 76.50 m long and 11.40 m wide barge.

At the comparative velocity of 12 km/hr the resistance reductions following figure 5. are:

convoy	1	12.0 %
convoy	2	6.0 %
convoy	3	2.0 %

The RESISTANCE- and POWER REDUCTION are velocity dependent. They are substantial in the case of the single tier, twin-section formation, since the bowform modification, without restriction by barges abreast would be fully effective fore and aft. Important is however that improvements with up to three tier 6-barge convoys still can be found.

The really relevant savings in propeller power become only visible in the interaction of the bargeconvoy with the pushboat (refer to figure 5a) as follows:

convoy	1	14.3%
convoy	2	8.6%
convoy	3	????

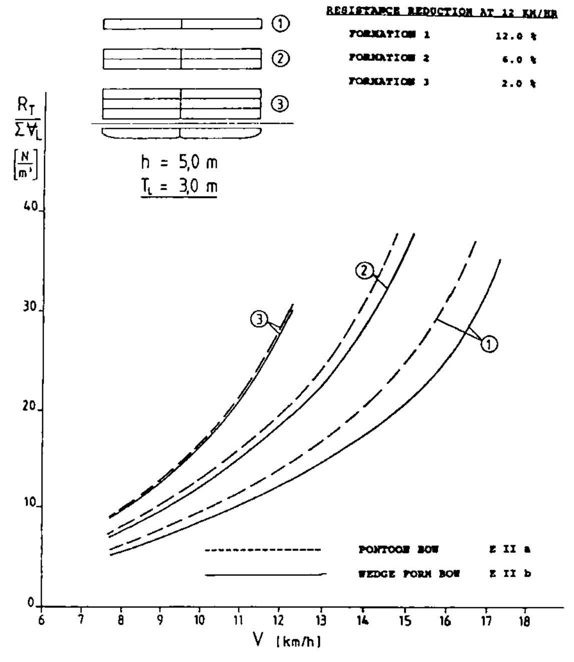


fig. 5. Specific resistance of barge only-formations with E II a and E II b barges

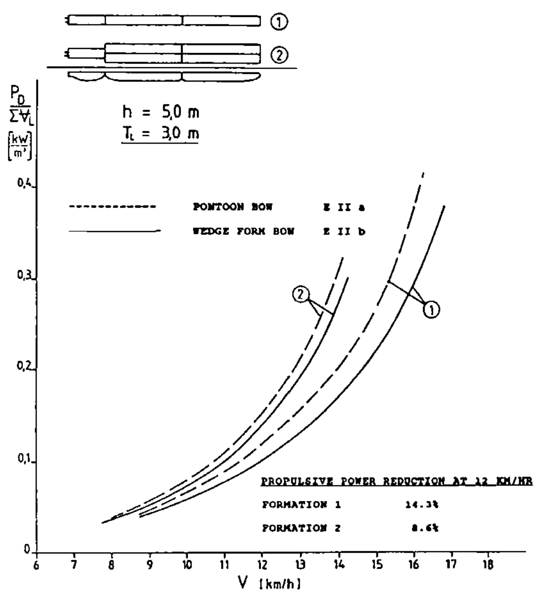


fig. 5a. Specific resistance of Pushboat-barge formations with E II a and E II b barges

It is clear, as repeatedly confirmed, that the energy savings are larger than the resistance reduction. This is mainly based on the fact that the effective ratio

convoy length to convoy beam

increases with the pushboat added, and thus becomes more favourable.

This must be even more notable with larger beam convoys. In addition to this comes, in the case of multiple-tier convoys, the reduction of the energy consuming wake turbulence as effectuated by the pushboat body.

Moreover should -at least with single and still with double tier convoys- improved inflow conditions for the propeller, tend to an increase in propeller efficiency.

With increased draught of the barge and shallower waters, and consequently with reduced underkeel clearance, a clear gain in power saving with the new bow shape is effectuated.

Depending on the boundary conditions, power savings for one- and double tier convoys between 8% and 22% could be reached.

Of interest to the barge Operator is the fact that the pay load capacity of the E IIb barge, when fully loaded, is about 45 tons higher is than the original shape of the barge type E IIa.

<u>example 2</u>
<u>juggernaut barge</u>

For propulsion energy saving in pushbarge operations of the future, concentration of cargo in large single barges would come into account. This topic has been subject to proposals by the VBD for more than 10 years.

A research report on the subject is at moment in its final phase (ref [10]). The results indicate that the barge Operators should occupy themselves with the question whether the procurement of juggernaut barges would fit in the future substitution plans for their existing barge fleet.

The convoys made up with these barges would be exclusively bound for Rhine river traffic between Rotterdam and Karlsruhe.

Figure 6 shows the shape of this juggernaut barge in the version 100m length by 14 m width.

L • B • H = 100 * 14 * 4.0 m

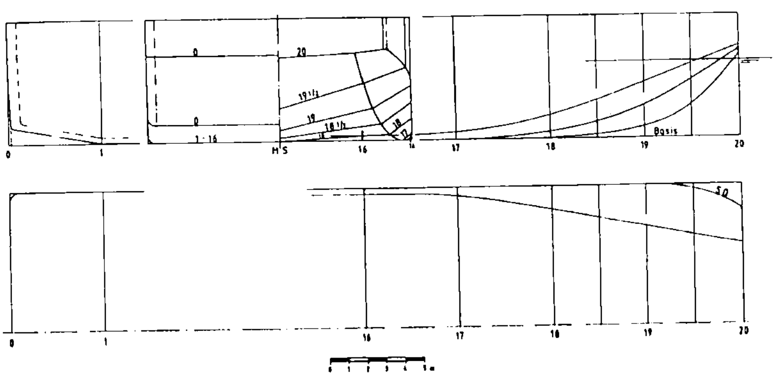
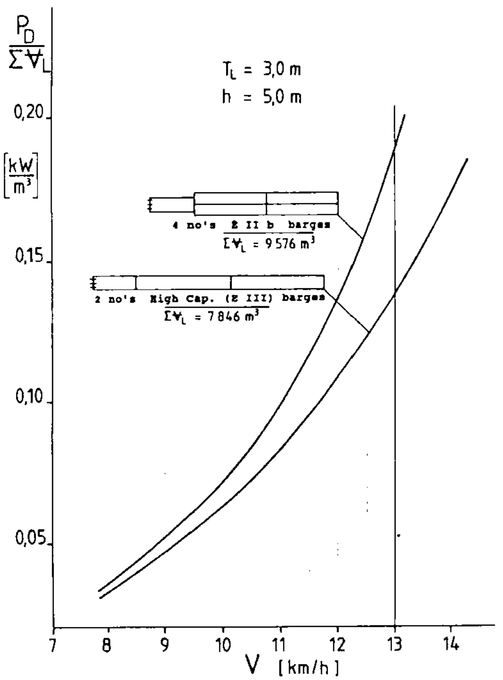


fig. 6. <u>High capacity varge (super barge) linesplan (future standard barge E III)</u>

In respect of the partially reduced transport quantities in the bulk trade and primary the growing container transport, are the load capacities as offered with the above barge dimensions certainly of interest. The new juggernaut barge would be able to transport at least 224 TEU in four stacks.

In figure 7 and 8 some essential research results of the juggernaut barge tests are displayed and compared to the E IIb barge formations.



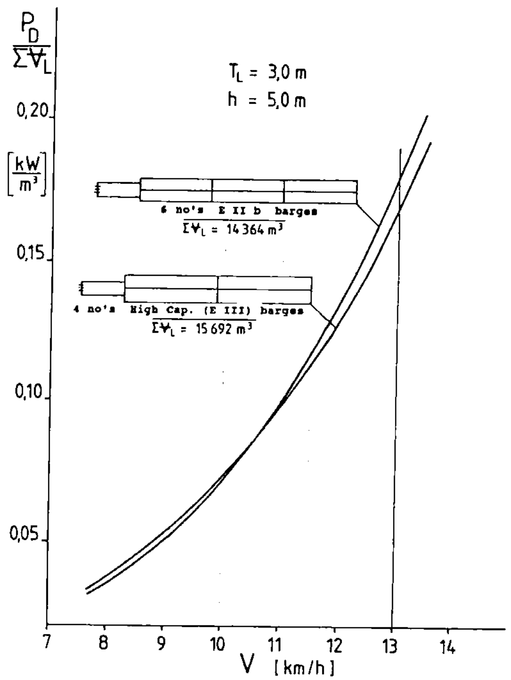


figure 7/ Specific power consumption of HC barge versus
figure 8 standard E IIb barge formations

When deploying 2 juggernaut barges in tandem configuration (= 1 tier formation) in stead of four standard barges in twin tandem configuration (= 2 tier formation), the energy saving per m3 of displacement when compared at a realistic speed of 13 km/hr, amounts to abt. 27 %. The 4 juggernaut barge formation compared to a 6 E IIb barge formation (in the most favourable 3 long, 2 wide configuration) arrives still at 6% energy saving.

The final elaboration of these extensive series of tests - additionally with modified dimensions of the juggernaut barge- will confirm the significant economic advantages of the twin-tandem configuration under all boundary conditions.

The convoy made up with 2 juggernaut barges, because of its absolutely lower power consumption, would permit a continued deployment of older pushboats with relative lower propulsive power.

Even with 4 m draught at 5m waterdepth would 2 x 800 kW be sufficient for a speedy and traffic-safe handling of barges.

example 3
Inland Cargo Vessel of the future

With this broad characterization an extensive Research & Development program is at moment being executed in the FRG.

Financed by the Federal Ministry for Research and Technology, the Federal Association of West German Inland Navigation and the participating Shipyards a triple objective is being pursued, being:

- **Optimization of the hydrodynamic quality of new building vessels.**

- **The elaboration of data for the weight optimized construction of such vessels.**

- **The development of resistance reducing and propulsion improving means for the existing inland cargo vessels.**

All three objectives are focused on improvement of the economic efficiency and the safety of traffic. Herewith, the efficient use of propulsive energy stands in front as an objective for development.

After important pre-research [11] the first partial objective, the optimization of the hydrodynamic quality of new building vessels, already leaded to marked results [12]

Starting with basic designs from the participating shipyards and the VBD, further development of HULL SHAPING was executed.

Also the influence of detail variants such as

propeller direction of rotation
nozzle construction
rudder installations

on power consumption were investigated.

Figure 9 shows as an example the possible energy saving with an optimum stern- and bow form, compared to an in praxis satisfactorily performing, large self propelled motor cargo vessel, which was designed following present day principles.

Total reduction of the specific resistance could be obtained -depending on waterdepth and vessels draught- between 1.5% and 34%. The average effective saving quotient lies between

It was also an objective of the R & D plan to determine the effect of an increase resp. reduction of the vessels' parallel midship section length, on the specific power requirements.

Figure 10 confirms that the energy saving per m3 of displacement as a result of length increase is noteworthy. It amounts for example to 7% for ships lengths between 110 and 125 m.

With the application however it should be observed that the vessels deadweight with unchanged width and depth, for constructive reasons percentage wise exceeds the increase in displacement resulting from the hull extension. The saving related to the payload amount, then ends up lower.

It can be stated that an increase of the permitted ships length up to 125 m for economic reasons, would be reasonably effective.

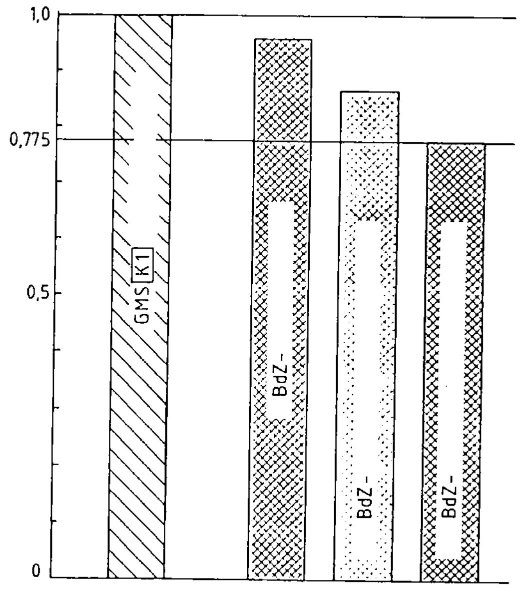


fig. 9. Energy saving with an inland cargo vessel of the future on basis of specific poiwer

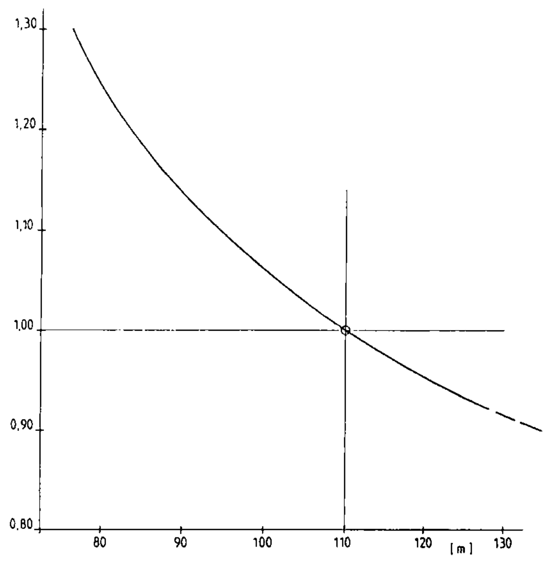


fig. 10. Energy saving per m3 of displacement with inland cargo vessel of the future on basis on the waterline lenght

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