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Remark: All symbols and equation completely base on international SI-Units in this article. The paper is written in British English.

ABSTRACT:

As a vessel moves through water it generates waves this being the first main problem of environmental impacts on banks. During the movement of a short and small watercraft secondary waves become significant due to the superposition of diverging and transverse waves. Maximum secondary wave heights H_{max} crucially influence the energy of a shoaling wave train and hence the impact on the bank. Since an increase of recreational boat traffic is to be expected, those effects become more important. The modified approach of Soehngen (2010) based on the empirical approximation by Maynord**,** with the consideration of the different operation modes**,** is the most convenient for estimating the expected wave heights. To realise a comparison with the calculated values, a concept of in-situ tests was developed. Therefore nearly 400 controlled runs were made with six different boats of various lengths (2.6 to 12.0 m). The boat speed and the location of the sailing lane were varied with the purpose of surveying the performance in different water depths. With diverse wave gauges wave heights could be measured at several distances to the sailing lane. The largest secondary waves were observed during the semi-planing mode. Using the collected field data an analytical comparison to the calculated approximation can be realised. Specific relations to the wave theory are found and discussed.

In addition to the secondary wave generation, the second main problem of a running boat has to be explored. Which hydraulic load caused by propulsion is possibly generated beyond a boat, especially in shallow waters? In order to clarify this question, bollard pull tests were conducted.

Finally, the approaches and models validated for inland water vessels also principally apply for recreational boats. However, some modifications must be done. Soehngen's / Maynord's approach has to be modified and extended. All three driving states of a boat (displacing, semi-planing, planing) can be described with empirical formulae. The boat's displacement and its velocity are the main factors. The effect of the propulsion strongly depends on the propeller characteristics, the wake factor and the induced initial velocity.

KEY WORDS: environmental impact of leisure boats, maximum secondary waves, propulsion, wake factor, prognosis model

1 INTRODUCTION

Moving or manoeuvring boats induce a variety of hydrodynamics effects and forces having different impacts on banks, flow, sediments as well as different ecological influences based on significance, affected species groups, prevention and mitigation (PIANC, 2008). From a hydraulic engineering standpoint, waves on banks and loads caused by boat propeller wash are mainly environmental impacts of vessels. Especially in consequence of inland water transportation big waves are often generated. The primary waves of large motor vessels are normally transmitted to the river's or canal's bank. In contrast during the movement of a short and small watercraft, secondary waves become significant because of the superposition of diverging waves generated at the bow and transversal stern waves. The strongest effect of boat-induced waves occurs on banks, and is most important as resulting erosion processes destroy bank or shore structures in a sustained fashion. That is primarily of importance in shallow waters or in ecologically valuable segments.

In Europe and Germany it can be observed that the recreation navigation is growing in importance for some years. Especially the large waterways in Germany (Rhine, Danube and Elbe Rivers) as well as small river systems (Havel or Spree River around the capital Berlin), natural lake districts (Bodensee, Mueritz) and restructured opencast mining lakes (Central Germany – Leipzig, Lusatian Lakeland) are becoming even more popular. Therefore the main question is whether and to what extent leisure boats play a largely role in impacting bank and bed structures. For that reason, driving tests with different boats types and with nearly 400 controlled runs were performed nearby Berlin (Untere Havel-Wasserstraße) in 2012. This location was selected due to its large offer of different boat types (ca. 50,000 boats, i.e. the highest density of boats per km² 435 – 933 boats/km² in Germany) and optimal test section (nearly linear bank line, deep and relatively shallow water, very weak bed slope) could be found. To get satisfying results some substantial working points stood in the focus of interest:

- Which relevant types of leisure boats are typical for inland recreation navigation (dimensions, motor power)?
- Which kind of boat induced waves can be measured?
- Which thrust is measurable by using bollard pull tests to interpret the propulsion effect?
- Are the measured values describable and predictable by established approaches?
- What is the influence of water depth (shallow water effect) on wave making?

The last question is still under consideration. Not all measurements are analysed. Therefore this paper focusses on deep water conditions and first results with one typical boat.

2 RELEVANT TYPES OF BOATS AND THEIR CHARACTERISTICS

Based on a statistical investigation (Mell, 2008), it can be assumed that approx. 300,000 motor boats exist in Germany, whereby nearly 115,000 small open motor boats and 190,000 motor yachts can be distinguished. Approximately 77 % of them possess an inland port as berth. A good criterion for a categorisation into different types is the boat length (L_B). A boat length of nearly L_B = 7.0 m can be identified as the mostly frequent one in inland waters (22 %). This value also appears as a good overriding criterion between small sport boats (< 7.0 – 8.0 m) and motor yachts (> 7.0 – 8.0 m).

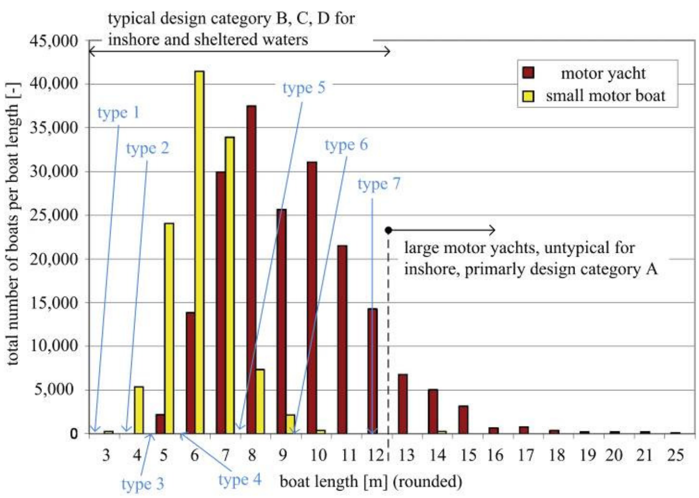

Figure 1 Statistical distribution of the motor boat length (L_B) in Germany (Mell, 2008)

To represent the typical statistical distribution (see Table 1 and Figure 1) it has been considered useful to divide the range of values of L_B into seven relevant classes (1 – 7). Unfortunately it was not possible to charter any type 5 boat with a length of 7.0 – 8.0 m. Finally six different boats (types 1, 2, 3, 4, 6, 7) were selected and used for the driving test procedure. The technical data and the boat characteristics are indicated in Table 1 and Figures 2 – 7, as follows, whereby L_B, B_B and T_B [m] represent the boat length and width at waterline level and the draught of the hull, respectively.

Table 1 Selected boat types 1 – 7 and their technical characteristics

Type [-]	Name [-]	CE-Category [-]	Gross weight [kg]	L_B [m]	B_B [m]	T_B [m]	D [m]	P [m]	max. speed $v_{B,max}$ [km/h] [(m/s)]	Hull form [-]	Block coefficient c_B [-]
1	Typhoon	D	221	2.60	1.50	0.16	0.19	0.18	9.4 (2.6)	planing boat	0.35* 0.22**
2	Avon R340	D	271	3.10	1.60	0.30	0.24	0.28	31.7 (8.8)	planing boat	0.18
3	Galia 475	C	838	4.50	1.95	0.47	0.24	0.20	9.7 (2.7)	planing boat	0.20
4	Larson LX 850	C	1,310	5.35	2.24	0.60	0.39	0.38	50.4 (14.0)	planing boat	0.18
5***	---	---	---	---	---	---	---	---	---	---	---
6	Christo Mare	B	4,460	9.50	3.00	0.85	0.48	0.42	28.1 (7.8)	semi-planing boat	0.18
7	Gina Carina	B	10,160	12.00	3.96	1.05	0.56	0.53	19.1 (5.3)	displacement boat	0.20

*2 persons aboard **1 person aboard ***further investigation necessary D, P: propeller diameter and pitch

Figure 2 Boat type 1 – rubber dinghy "Typhoon 310 Aero", 2-stroke-outboard engine (petrol), power 3.7 kW

Figure 3 Boat type 2 – inflatable dinghy "Avon R340", 4-stroke-outboard engine (petrol), power 11.0 kW

Figure 4 Boat type 3 – motor boat "Galia 475", 4-stroke-outboard engine (petrol), power 5.9 kW

Figure 5 Boat type 4 – motor boat "Larson LX 850", 4-stroke-inboard engine (petrol), power 99.3 kW

Figure 6 Boat type 6 – motor yacht "Christo Mare", 4-stroke-inboard engine (diesel), power 110.3 kW

Figure 7 Boat type 7 – motor yacht "Gina Carina", 4-stroke-inboard engine (diesel), power 125.0 kW

The gross weight includes the net weight, the engine and additionally two persons. The values D [m] and P [m] are the propeller's diameter and pitch. All boats possess normal single propellers (no ducted propellers).

The boat types mentioned above represent good examples of motor boats in Germany's inland waters. According to the CE-Classification (European Union Directive 765/2008 and 2003/44/EG – "seeworthiness", essential safety requirements [EU, 2003]) all selected boats are classified in the boat design category B (offshore), C (inshore) or D (sheltered waters). Large motor yachts with a length of more than 12.0 – 13.0 m are rather untypical and very rare in inland due to their draught or installation height and width, which is the reason why they were consequently disregarded in further research. Such types normally attributed to category A (ocean) can be regularly encountered offshore or at sea.

The analysis of the characteristic block coefficient c_B (remark: c_B represents the ratio between the static boat displacement ∇ [m³] and the volume of a covering rectangular parallelepiped, determined from the overall dimensions $V = L_B \times B_B \times T_B$ [m³]) shows (Table 1), that in contrast to Maynord (Maynord, 2005) this parameter typically varies between $c_B = 0.19 - 0.20$ for inland sport boats. Maynord uses $c_B = 0.40$, taking the length L and breadth B of the boat in the water line (not overall). It should be noted that this value seems to be too high for typical planing boats in Germany. Therefore, a value of $c_B = 0.20$ is used.

3 TEST AREA, TEST PROCEDURE AND EQUIPMENT

The selected test area was located on the eastern side of the River Untere-Havel-Wasserstrasse between Berlin and Potsdam, Germany. This area resembles a lake habitat, with a total width of approx. 1,000 m; the flow velocity is very low and tends to $v = 0$ m/s. The bank inclination of the measuring section shows a significantly flatter slope ($1 : m = 1 : 40$). Beyond a bank distance of more than 90 m a water depth (h) of 2.50 m can be identified. The test section consists of a measurement section as well as an accelerating and brake distance. At first, seven boat lanes (FS-1 – FS-7) were marked with moored buoys and positioned in parallel with defined distances (u) to the bank and water depths (h). Perpendicular to these lanes and for a double data logging, two measurements transects (T_I, T_{II}) with seven capacitive levels (KM 2 – KM 8), two acoustic wave and current levels (AWAC1/2) and two ultrasound levels (US1/2) were installed (see Figure 8). The value x defines the perpendicular distance between the boat axis and the measurement level, whereby $+x$ [m] means the direction to the bank and $-x$ [m] defines the opposite side to the open lake.

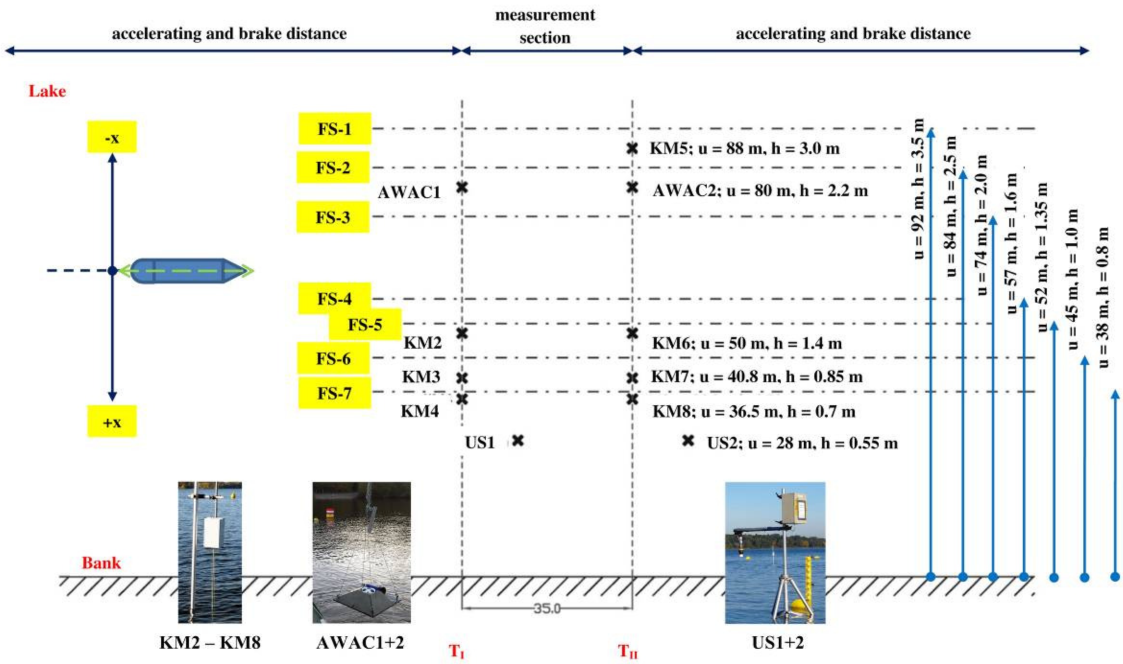

Figure 8 Test area with definitions and positioning of levels, boat lanes and distances

Figure 9 Bollard test, left: used dynamometer, right: test procedure with inflatable dinghy “Avon R340”

The adjustment of lanes FS-3 (minimum for boat type 7), FS-4 (minimum for boat type 6), FS-6 (minimum for boat type 4) and FS-7 (minimum for boat type 3) were carried out for verifying the basic condition h/L_B = 0.15 … 0.20 m (shallow water criterion). These lanes concurrently offered the possibility of driving with minimum and absolutely critical water depth plus 20 cm keel clearance ("Flottwasser"). Fairway depths below these were not recommended for these boat types due to their draught and the potential danger of running aground. Lanes FS-1 and FS-2 were provided to regard deep water conditions. Lane FS-5 only served for another refinement of the measuring grid. Given that boat types 1 and 2 possess outboard engines, motor draught is more relevant than hull draught in this case. For that reason, a minimum fairway depth of 50 cm results for avoiding any grounding. Finally FS-7 represents the lane closest to the bank.

Then, nearly 400 controlled and registered runs on these seven lanes with different boats and speeds were carried out. Inside of the measurement section (Δl = 35 m, see Figure 8) the run time was registered. Finally the boat speed could be determined. Depending on the achievable velocity the wave data were logged time-dependently and for different locations perpendicular to the boat lane. After the trials, all data were prepared for further analysis.

Additionally to the test runs for determining the speed-depending maximum, wave height bollard pull tests were conducted (see Figure 9). By usage of round slings the boats were fixed with a bollard. The sling capacity was 40 kN and its length could be adjusted variably. To obtain the boat's thrust, a dynamometer was fixed between boat and bollard. During the pull procedure the motor revolution was increased slowly up to the maximum and the propeller rotation (n [rpm]) as well as the shown pull load = boat's thrust (T [kN]) were registered for further analysis. The gear ratio was known, thus allowing the computation of the propeller's rotation.

4 WAVES CAUSED BY MOVING BOATS

Observable and measurable secondary waves in deep water caused by moving vessels primarily depend on the following main parameters:

- hull form (describable e.g. by the boat displacement (∇ [m³]) and its speed-depending change),
- speed of the boat (v_B [m/s]),
- perpendicular distance to the boat axis (x [m]) and
- water depth (h),

whereby the maximum wave height (H_{max} [m]) is defined as the maximum distance between wave crest and trough. It is generally the most interesting value within an observable boat-induced wave spectrum. As an example Figure 10 shows measured for the motor boat type 4 "Larson LX 850" values of H_{max}, depending on boat speed v_B in a perpendicular distance of $x = 7$ m from the boat axis. Shallow water effects are not relevant.

Figure 10 illustrates three different speed ranges: An increasing curve ①, which represents the displacement drive. The wave height is increasing progressively with speed. This speed range is generally limited by the planing speed $v_{gl,1} = 1.1 \cdot (g \cdot \nabla^{1/3})^{0.5}$ [m/s] (Soehngen, 2010) where the increase of wave heights stops and stays nearly constant over a short range of boat speed. Starting at about $v_{gl,2} = 1.3 \cdot (g \cdot \nabla^{1/3})^{0.5}$ [m/s] (Soehngen, 2010); a decreasing curve ③ that includes the state of full planing is shown on the right side of Figure 10 (remark: g [m/s²] represents the gravity acceleration). Due to decreasing drive resistance the resulting wave height declines with increasing velocity. The transitional section ② between state of displacement and planing (between $v_{gl,1}$ and $v_{gl,2}$) is called semi-planing, whereby the drive resistance starts to become lower. The realised test runs showed that the change between different driving states often happened in a sudden jump (especially from ① to ③ between $v_{gl,1}$ and $v_{gl,2}$). It was relatively hard to maintain the exact required boat velocity in the transitional section ② for getting some usable measured values inside of this range.

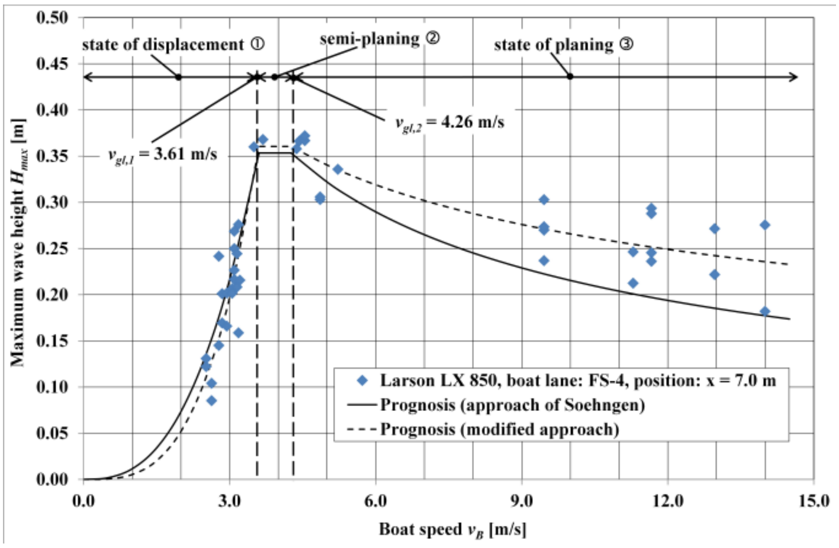

Figure 10 Example of measured maximum wave heights (H_{max}) and prognosis for type 4 “Larson LX 850” (depending on boat speed (v_B) and position x = 7.0 m)

Noelle (Noelle, 2012) compared different approaches for prognosis models of the wave height H_{max} for deep water conditions. Accordingly to this analysis the best general compliance with drive tests in the state of planing ($v_B \geq v_{gl,2}$) was firstly developed by Maynord’s empirical formula for $H_{max,May}$ (Maynord, 2005) as follows (equation 1):

$$H_{\max,May} = C \cdot \nabla^{1/3} \cdot Fr_{\nabla}^{-0.58} \cdot \left(\frac{x}{\nabla^{1/3}}\right)^{-0.42} \quad (1)$$

with $C = 0.82$ [-] (flat hull / semi-planing / planing) to C = 1.0 [-] (full bodied boat / displacer), concerning the observed waves from US fishing boats.

Soehngen (2010) has validated and optimised this empiric approach by exploiting scale model experiments. By usage of $C = 0.82$ [-] and $Fr_{\nabla} = 1.3$ [-] (beginning of full planing) he extended Maynord’s approach to all states of driving as written:

displacement mode ①:	$H_{max,(1)} = (v_B/v_{gl,1})^{b_{(1)}} \cdot H_{max,May}$	(range $Fr_{\nabla} = 0 - 1.1$),
semi planing mode ②:	$H_{max,(2)} = H_{max,May}$	(range $Fr_{\nabla} = 1.1 - 1.3$),
full planing mode ③:	$H_{max,(3)} = (v_B/v_{gl,2})^{b_{(3)}} \cdot H_{max,May}$	(range $Fr_{\nabla} \geq 1.3$),

where the auxiliaries are set to $b_{(1)} = 8/3 \approx 2.667$ and $b_{(3)} = -0.58$.

Figure 10 shows a reasonably good correlation between estimated and measured data from the test runs primarily for ①. However, for the state of full planing ③ considerable differences are noticed so that modifications seem to be necessary for the test boat in Figure 10 (modified approach). Regarding the formulas of Maynord and Soehngen and based on the investigations in progress it can now be written in a modified general form

displacement drive ① ($v_B \leq v_{gl,1}$ respectively $Fr_{\nabla} < 1.1$):

$$H_{\max,(1)} = a_{(1)} \cdot \left(\frac{v_B}{v_{gl,1}}\right)^{b_{(1)}} \cdot \left[\underbrace{C \cdot \nabla^{1/3} \cdot 1.3^{-0.58} \cdot \left(\frac{x}{\nabla^{1/3}}\right)^{-0.42}}_{H_{\max,May}(Fr_{\nabla}=1.3)}\right] \quad (2)$$

planing drive ③ ($v_B \geq v_{gl,2}$ respectively $Fr_\nabla > 1.3$):

$$H_{max,(3)} = a_{(3)} \cdot \left(\frac{v_B}{v_{gl,2}}\right)^{b_{(3)}} \cdot \left[\underbrace{C \cdot \nabla^{1/3} \cdot 1.3^{-0.58} \cdot \left(\frac{x}{\nabla^{1/3}}\right)^{-0.42}}_{H_{max,May}(Fr_\nabla = 1.3)}\right] \quad (3)$$

The today's state of analysis shows that for the example "Larson LX 850" the best correlation between prognosis and measurement can be achieved with a modified Soehngen approach for the displacement ① and planing mode ③. The particular auxiliaries for the example "Larson LX 850" (also see Figure 10) are shown in Table 3. As a planing boat the parameter C = 0.82 was used in this case.

Table 3 Fitted auxiliaries for equation (2) and (3) by using the example in Figure 10

	Auxiliaries for equation (2)	
	$a_{(1)}$ [-]	$b_{(1)}$ [-]
approach of Soehngen	1.00	2.6667
modified approach for "Larson LX 850"	1.02	3.2859
	Auxiliaries for equation (3)	
	$a_{(3)}$ [-]	$b_{(3)}$ [-]
approach of Soehngen	1.00	-0.580
modified approach for "Larson LX 850"	1.02	-0.357

To formulate the transition condition for the semi-planing state ② ($v_{gl,1} \leq v_B \leq v_{gl,2}$ respectively $1.1 \leq Fr_\nabla \leq 1.3$) a mathematical description by using a flat rounded polynomial approximation can be used (e.g. $H_{max,(2)} = a \cdot v_B^4 + b \cdot v_B^3 + c \cdot v_B^2 + d \cdot v_B + e$) where correct basic conditions (e.g. the same function value: $H_{max,(1)}(v_{gl,1}) = H_{max,(2)}(v_{gl,1})$; $H_{max,(2)}(v_{gl,2}) = H_{max,(3)}(v_{gl,2})$ as well as the same slope of the curve: $d/dv[H_{max,(1)}(v_{gl,1})] = d/dv[H_{max,(2)}(v_{gl,1})]$; $d/dv[H_{max,(2)}(v_{gl,2})] = d/dv[H_{max,(3)}(v_{gl,2})]$) should be regarded. However, ongoing investigations have shown that the wave height can be approximately set as constant (plateau) $H_{max,(2)} \approx H_{max,May}(Fr_\nabla = 1.3)$.

5 BOLLARD PULL TESTS, THRUST AND PROPULSION

Figure 11 shows the results of the achievable thrust values depending on the propeller's rotation. It can be clearly seen that boats with high power also reach high thrust values. Also visible is the tendency of higher power engines combined with big propellers and high rotations to induce strong hydraulic loads on the bed caused by propulsion. This impact cannot be underestimated. Furthermore, it must be admitted that different engines (2-stroke petrol, 4-stroke petrol, 4-stroke diesel) with different power curves have been used and compared.

However, mainly the effect of the propulsion strongly depends on the propeller characteristics, the wake factor and the propeller induced initial velocity, whereby thrust is an important input parameter. According to BAW (BAW, 2004) the induced initial velocity (v_{0J}) of a moving inland freight vessel (free wheel) can be determined as follows (0.6 < P/D < 1.4, [Kornev, 2009])

$$v_{0J} = \sqrt{\left(J^2 + 2.55 \cdot k_{TJ}\right)} \cdot f_N \cdot D \cdot \frac{n}{60} \quad (4)$$

where J [-], k_{TJ} [-], f_N [-], D [m] and n [rpm] represent the rate of advance, the thrust coefficient, a constant coefficient $f_N = 0{,}75$ (for normal propellers), propeller diameter and propeller rotation per minute. P [m] stands for the pitch of the propeller. The rate of advance decreases to zero if the vessel's speed also tends to 0 and finally the induced initial velocity v_0 of a stationary boat remains. J for a moving vessel defines the ratio in formula (5) as

$$J = \frac{60 \cdot v_B \cdot (1-w)}{n \cdot D} \quad (5)$$

where v_B [m/s] represents boat speed (relative to water).

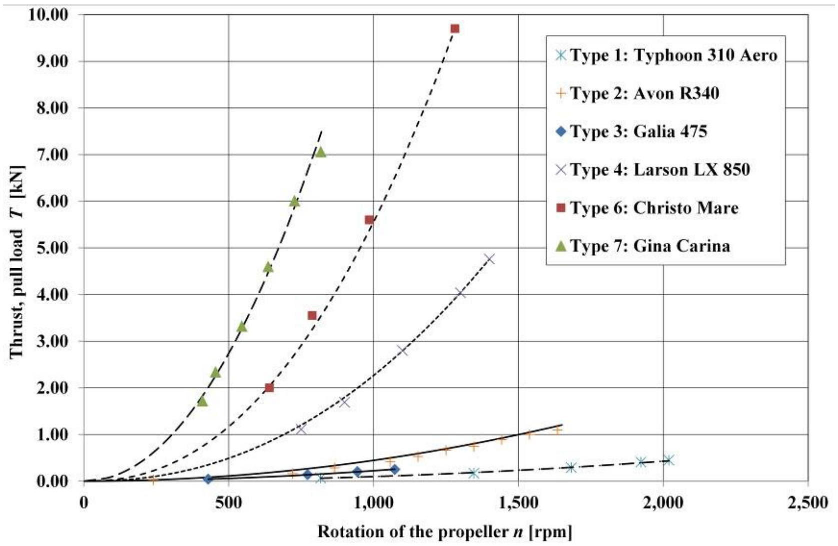

Figure 11 Results of the bollard pull test; thrust vs. propeller's rotation

Furthermore, as a boat moves through the water the flow into the propeller is strongly influenced by the boat hull and its appendages. As a result of that the advance velocity of the propeller is less than the speed of the boat. This effect is called the "Wake Factor" $(1 - w) \leq 1.0$, and it includes the Wake Fraction $w \leq 1.0$. The parameter w normally needs to be determined by complex experiments. This problem is a typical field of activity of the ship-/boatbuilding research and industry.

To simplify that issue and based on diverse experiments, BAW (BAW, 2004) indicates for inland ships a value of $(1 - w) \approx 0.7$ ($w = 0.3$). Due to completely different hull forms it is not useful to apply this to motor boats and yachts. Other references also show that this value (0.7) is too low. In summary, the following "Wake Factors" can be recommended based on miscellaneous references (e.g. Phillips-Birt, 1957; SNAME, 1967; Stanton, 1975; Gerr, 1989):

1. Outboard or inboard/onboard powered boats: $(1 - w) \approx 0.95$
2. Flat or V-Bottom hulls – one or two propellers: $(1 - w) \approx -0.0001 \cdot v_B^2 + 0.0065 \cdot v_B + 0.91$ (v_B set in [m/s] with $v_B \leq 19.5$ m/s)

Contrary to inland ships the "Wake Factor" of motor boats / motor yachts are significantly higher and grow for high velocities toward to 0.96 – 1.0 which is characteristic for planing boats and decreasing driving resistances. It should be noted by using equation (5).

In formula (4), k_{TJ} is one of the main input parameters. BAW (BAW, 2004) recommends the empirical approach for its determination shown in equation (6)

$$k_{TJ} = A \cdot \frac{P}{D} + B \cdot J \quad (6)$$

with $A = 0.55$ and $B = -0.46$ verified by inland ships. Regarding the validity of the propeller law the factor k_{TJ} can be also mathematically expressed as (for $0.6 < P/D < 1.4$, [Kornev, 2009])

$$k_{TJ} = \frac{T}{\rho_w \cdot n^2 \cdot D^4} \quad (7)$$

in which ρ_w [kg/m³] represents the density of water ($\rho_w \approx 1{,}000$ kg/m³). If we now assume the validity of equation (6) and (7) and both formulas are equated, the empirical auxiliary *"A"* can be determined by using the rotation-dependant thrust *“T”* for $J = 0$ ($v_B = 0$) (also see Figure 11). The following Table 4 shows the corresponding arithmetic means. Due to the non-moving procedure it is noted that the value *“B”* cannot be verified by the bollard pull tests. Until now it must be assumed that *B* is also valid for this investigation of motor boats and yachts or it has to be characterised by an approximation.

Table 4 Arithmetic averages of *“A”* (equation (6))

Type	1	2	3	4	5	6	7
Name	Typhoon	Avon R340	Galia 475	Larson LX 850	---	Christo Mare	Gina Carina
A	0.30	0.38	0.31	0.35	---	0.43	0.43

Table 4 illustrates that the empirical value is not constant as BAW (BAW, 2004) proposes for inland freight vessels. It is also lower than 0.55 for motor boats and motor yachts. The today’s state of research would seem to indicate that a value of $A = 0.30 \ldots 0.35$ should be used for small boats with planing hulls. For large yachts (semi-planing, displacement hulls) the value of $A = 0.40 \ldots 0.45$ would be appropriated to calculate the propulsion effect caused by propellers.

6 CONCLUSIONS

Nearly 400 driving tests and some bollard pull tests with assorted motor boats and yachts were carried out in order to explore the wave loads on banks and propulsion loads on beds. The questions that were addressed were: What are typical motor boats for inland, primarily in Germany/Europe? Which kinds of secondary waves could be observed and measured? Which effect of propulsion could be expected? Are the known approaches applicable? Especially due to geometric characteristics (boat length, width, draught) the size of leisure boats in inland waters is limited as the statistical consideration clarifies. Today’s state of research shows that the published approaches for waves and propulsion caused by inland ships are also valid for smaller motor boats and yachts in principle. However, the hull characteristic, the achievable velocity and the possible states of driving partially differ in an extensive way contrary to inland ships. Therefore some parameters and auxiliaries have to be modified, such as block coefficient, wave formula or thrust coefficient.

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References

BAW, 2004. Grundlagen zur Bemessung von Böschungs- und Sohlensicherungen an Binnenwasserstraßen, Mitteilungsblatt Nr. 87, Federal Waterways Engineering and Research Institute, Karlsruhe, Germany

EU, 2003. Directive 2003/44/EC of the European Parliament and of the Council of 16 June 2003. L 214/18, published 26.8.2003, Bruxelles, Belgique

Kornev N., 2009. Propellertheorie. Universität Rostock, Fakultät für Maschinenbau und Schiffstechnik, Rostock, Germany

Maynord S.T., 2005. Wave height from planing and semi-planing small boats. In: River Research an Applications, 21, ed. Jophn Wiley and Sons. Ltd., 1-17, USA

Mell W.-D., 2008. Strukturen im Bootsmarkt. FVSF-Forschungsbericht Nr. 1, Forschungsvereinigung für die Sport- und Freizeitschifffahrt (FVSF). Köln, Germany

Noelle M., 2012. Wellenbelastung durch Freizeitschifffahrt – Erarbeitung von rechnerischen Grundlagen sowie Entwurf eines Versuchskonzepts für Naturuntersuchungen. Diploma Thesis, unpublished, Technische Universitaet Dresden, Institute of Hydraulic Engineering and Technical Hydromechanics, Germany

Phillips-Birt D., 1957. The Naval Architecture of Small Craft. Published by the Philosophical Library, Inc. 1957, USA

PIANC, 2008. Considerations to reduce environmental impacts of vessels. Report n° 99 – 2008, PIANC Secrétariat Général, Bruxelles, Belgique

Gerr, D., 1989. Propeller Handbook. International Marine Publishing Company, USA
SNAME 1967, Principles of Naval Architecture. Published by the Society of Naval Architects and Marine Engineers, edition 1967, USA
Stanton J., 1975. Theory and Practice of Propellers for Auxiliary Sailboats. Cornell Maritime Press, USA
Soehngen B., Pohl M., Gesing C., 2010. Bemessung von losen Schüttsteinen gegen schiffsinduzierte Strömungen und Wellen. In: Dresdner Wasserbauliche Mitteilungen, Institute of Hydraulic Engineering and Technical Hydromechanics. Technische Universitaet Dresden, Germany, proceedings 40, 137-149