Devices improving the manoeuvrability characteristics of ships

Part I
Laboratory tests on models in cavitation tunnel and towing tank

Jerzy W. Doerffer, Prof.
Gdansk University of Technology

ABSTRACT

An account of research activities on the devices improving the manoeuvring abilities carried out at the Gdansk University of Technology is reviewed. These devices could be placed on the bulbous bow (opening bulbous bow) and at the stern end (wake pressure equalising device, stern shield, opening rudder). Researches with segments of models of these devices in a cavitation tunnel and on self propelled models of ships in a towing tank were performed as well as on open lakes.

Keywords : opening balbous bow, opening rudder, stern shield, steering braking device, braking the ship

INTRODUCTION

Collisions, ramming and grounding amount to about seventy percent of all the ship's casualties. Officially they were mainly attributed to human factor, but the lack of appropriate manoeuvring characteristics is not allowing the master to correct his navigational mistakes.

Therefore it was advocated to start an extensive programme on manoeuvring standards. From the safety point of view the most important are :

★ head reach while braking the ship without any side transfer
★ turning diameter.

Considerable number of accidents could have been avoided, if the manoeuvring characteristics could be improved. Inertia braking the ship and reversing the propeller are the only means of lowering the speed and stopping the ship. A stern rudder is the only device for changing the course of the ship and a side thruster additionally at harbour speeds on some ships. No special devices are used on commercial transport ships to improve the manoeuvring abilities despite increasing congestion on shipping lanes and traffic routeing. Inertia braking is a very lengthy procedure, the ship looses her speed due to the resistance of water and wind and thus the head reach is exceedingly large. Reversing the propeller is also a lengthy procedure, on some large diesel engine takes at least 30 seconds and sometimes even up to one minute. On a steam turbine ships this operation takes over one minute. Reversing the propeller results in considerable loss of power astern as compared with running forward (diesel engine about 15% and steam turbine about 60%). This is assisted by a steering moment, which makes the ship to deviate from the original course in an uncontrollable manner causing a side transfer up to 3 x ship lengths. Propeller working astern causes high vibrations, which are most unpleasant for the crew and in case of resonance may cause fatigue damage to ship's structure and her outfit.

On large steam driven tankers the head reach from service speed to full stop amounted to over 15 x the length of the ship and the side transfer to over 3 x the length of the ship. Turning diameter was well above 4 x length of the ship. It was quite obvious that it is absolutely necessary with routeing the ship lanes that the ship would comply with the minimum standards worked out by this Subcommittee on Ship Design and Equipment and adopted by appropriate IMO bodies.

RESEARCH PROGRAMME

Very wide research programme concerning the improvement of steering characteristics was undertaken at the Gdansk University of Technology. The required improvement could not be achieved by modifications in existing devices and new devices had to be developed, being capable of generating large forces indispensable to destroy high kinetic energy of large ship proceeding at service speed in order to stop the ship. These devices should be also capable of creating large transverse forces to decrease the diameter of circulation. The following devices have been invented which were located in the fore end and after end of the ship :

☆ fore end - opening bulbous bow
☆ stern end - stern shield; steering and braking device; wake pressure equalising device.

First of all they were tested in a cavitation tunnel until promising results were achieved and only then fitted on several different self-propelled models, which were tested in a 250 m long and 12 m wide towing tank. When good results were obtained the models were brought to open water in order to prove the improvement in manoeuvring characteristics. A model of a „Panamax" 65000 TDW in the scale 1:24 was used most extensively (Tab. 1). It was hand controlled by a skipper sitting in the model, whereas some models operated on the open lake were radio remote controlled. These tests allowed to state that simple and quite inexpensive devices could be installed aboard new and existing vessels in order to radically improve the manoeuvring characteristics.

***Tab. 1.** Principal dimensions of a „Panamax" ship and model.*

Item			Ship	Model
Length overall	L_{OA}	[m]	218.6	9.200
Length between perpendiculars	L_{PP}	[m]	205.0	8.541
Length on water line	L_{WL}	[m]	214.6	8.940
Displacement	-	[m³]	-	4.200
Breadth	B	[m]	30.48	1.270
Draft : Forward	T_F	[m]	11.56	0.482
Aft	T_A	[m]	11.54	0.482
Block coefficient			0.807	0.807
Scale			**1:24**	

OPENING BULBOUS BOW

Bulbous bow on large ships lowers the resistance by 10 to 15%. Through opening the bulbous bow this effect would be dispensed with due to radical change in flow pattern round the bow. Additional increase in resistance is obtained due to the increase in head area of underwater section of the hull. Several methods of cutting the bow were tried, but finally transverse cutting to a certain depth on both sides of the bow and two longitudinal cuttings along both sides of plain of symmetry (Fig .1). This method of cutting gave a fixed centre part of the bulb [1] and two large side flaps [2], which could be hinged sidewards to an angle of 110°. The flaps at higher speeds when opened asymmetrically could be used as bow rudders. A side thruster [3] could be fitted in the centre part, which could be used at slow speeds when the bulbous bow is opened. The side flaps of the bulbous bow, when opened to an appropriate angle will increase the effectiveness of the side thruster. In fact at higher speeds a parallel side transfer of the ship could be achieved without changing the course. This happens by opening one bow flap and the stern rudder. Thus powerful side forces are created without any turning moment, giving a side transfer of the whole ship without any protrusion of the stern, what is occurring by rapid turning in order to avoid head collision.

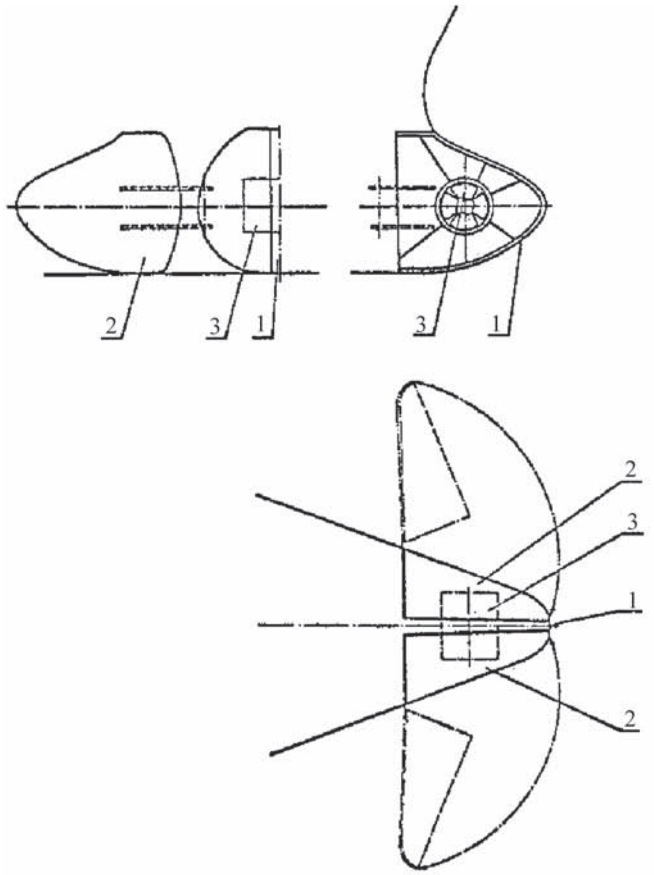

Fig. 1. Bow cutting of a model for experiments.

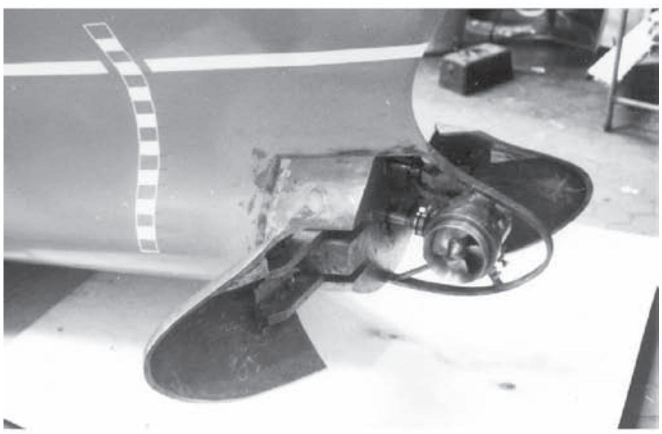

Photo of opened bow.

A very wide series of tests of opening bulbous bow were carried out in a cavitation tunnel. The aim of these tests was to establish the differences in resistance between a closed and opened bulb at different modes of cutting and angles of opening with respect to speed of flow and with regard to positioning the opened flaps in relation to the hull of the ship. These tests were to clarify the impact of following factors :

- area of flaps
- angle of opening of flaps
- width of centre part of bulbous bow
- shape of centre part
- internal stiffeners of the flaps
- proximity of opened flaps from the hull.

The results of these tests gave background to design and to test the opening bulbous bow on large scale self-propelled models of ships given in Tab. 2.

***Tab. 2.** Models of ships tested with opening bulbous bows.*

Type of ship	Displacement [m³]	L_{PP} [m]	B [m]	T [m]	Scale
Ro-Ro ship	38150	210.0	30.5	9.50	1:5
OBO ship	123700	236.0	38.7	15.00	1:24
Fishing vessel	322.6	49.5	-	2.20	1:12

The experiments conducted with these models confirmed great effectiveness in lowering service speed without any assistance from the main engine drive. The energy required to open the flaps is extremely low, as the flow of water is forcing the flaps to open and the hydraulic installation is needed for control of their synergetic movement. The flaps could be opened and closed at service speed symmetrically, when braking effect is required, and asymmetrically, when additional turning effect is necessary. At low speeds this device is ineffective for braking the ship and the flaps should be closed, because the wake of the ship running faster than the ship in process of braking, might drive the ship forward meeting opened flaps. Opened bulbous bow at harbour speeds increases the resistance of the ship and thus lowers the dead slow sustained speed, what is of significant importance for safety of harbour manoeuvres. Opened flaps and side thruster fitted in the bulb help the steering at very slow speeds.

STERN END DEVICES

The idea of utilising the force generated by redirecting the propeller wake momentum for braking and steering purposes of ships is not new. The first patents in this field were granted in the final years of XIX century. But these patents were never implemented on any large scale with the exception of jet propulsion applied to small and fast boats. This principle is widely used for braking aeroplanes.

First experiments were carried out with a model of a braking shield in a cavitation tunnel with a test section 0.3 m x 0.3 m. These experiments were to prove that the idea of redirecting the propeller wake momentum by means of a shield was a workable proposition for ships. It has shown many advantages such as :

- braking forces at service speeds, which were induced by the propeller, were approximately twice as big as the propeller thrust forward

- there was no need to reverse the direction of rotation of the propeller and thus no usual losses in power were to be considered. Additional advantage was the elimination of the reversing gear and on turbine ships there was no need to install the reversing turbine
- full course control could be exercised with ordinary rudder during the braking process
- very limited vibrations.

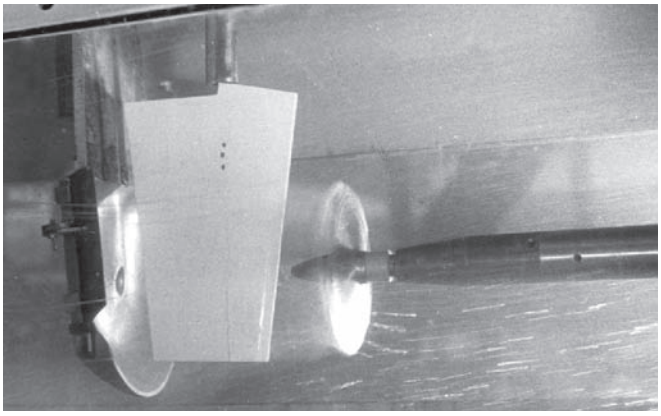

Photo of braking shield ZUH1 in cavitation tunnel.

The results were very encouraging and two devices were invented and a wide programme of research was carried out. These devices were :

- stern shields - two types (ZUH1 and ZUH2)
- steering and braking device – "Doerffer's Rudder" (SUH).

These devices are simple and easy to fit on any type of new or existing ship.

STERN SHIELDS

Two types of stern shields were invented :

- square profile shield (ZUH1) with bottom edge [1] rounded to fit the cross section of stern overhang, in which it is housed (Fig. 2).

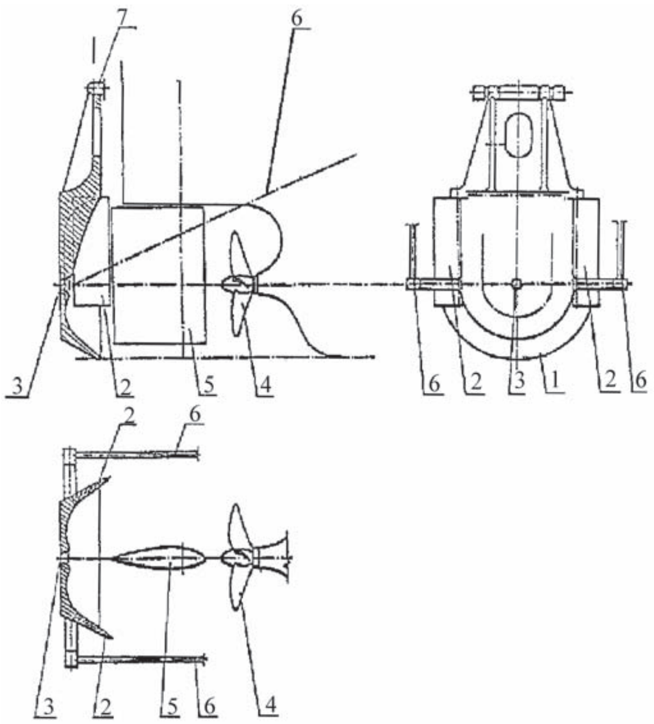

***Fig. 2.** Rectangular stern shield ZUH1.*

Two vertical straight side edges are provided with hinged vertical flaps [2] enabling the angle of outflow of propeller wake to be regulated from 0° to 90° for controlling the braking forces and by asymmetrical opening the flaps for creating a side force for auxiliary steering. Top edge is straight with an overhang forward. Shields are placed behind the propeller [4] and the rudder [5]. Thus no major modifications of ship's hull are required. The shield has a three point suspension consisting of two bottom stays of fixed length [6] fastened hinge wise to each vertical edge of the shield and to the ship's hull. Top attachment of the shield consists of one hinged bearing fastened to a sliding crosshead [7].
This mode of attachment allows lowering and lifting the shield by means of hydraulic lifting device within 10 seconds. In stowed position the shield is completely above the water matching the external lines of the ship and thus does not create any resistance.

- circular profile shield (ZUH2) of 190 mm diameter (1.6 x propeller diameter) of simplified design and without flaps (Fig. 3).

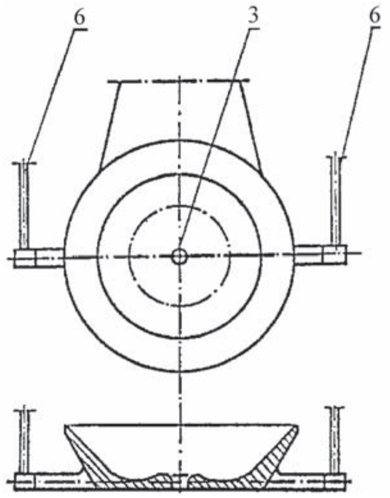

***Fig. 3.** Circular stern shield ZUH2.*

Both these devices were tested on the "Panamax" model at a steady propeller speed 750 min^{-1}. The results of these tests show great effectiveness of these devices (Fig. 4 & 5) as compared with inertia braking and propeller reversed at – 375 min^{-1}.

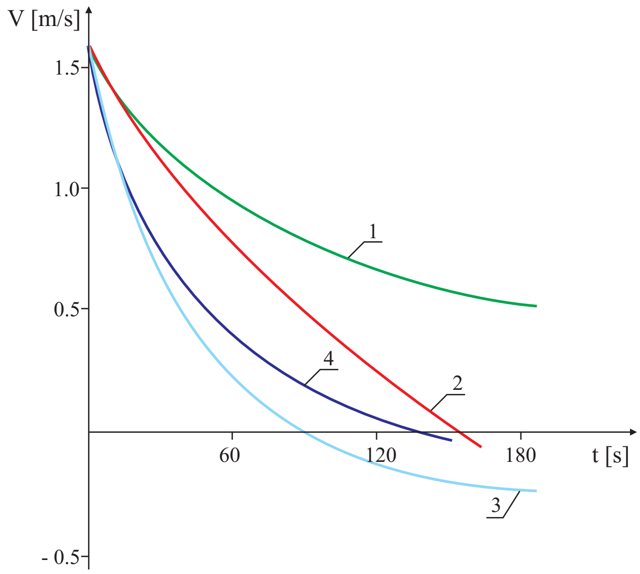

***Fig. 4.** Speed versus braking time. **1** – inertia braking; **2** – reversing the propeller 375 min^{-1}; **3** – ZUH1; **4** – ZUH2.*

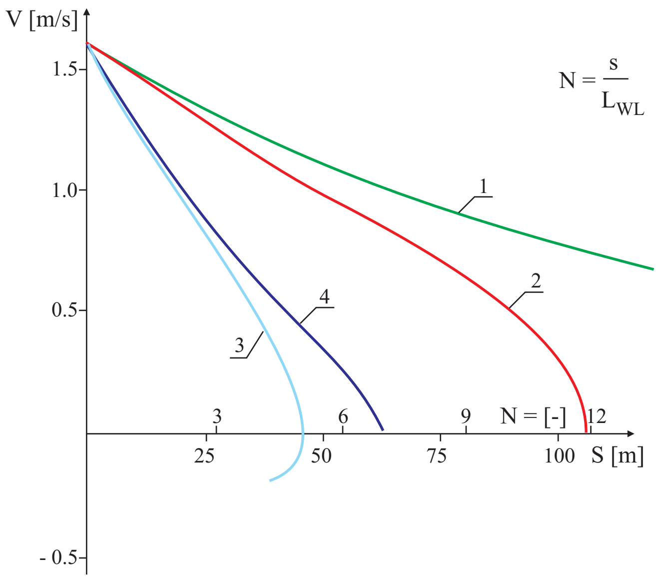

Fig. 5. Speed versus distance travelled. 1 – inertia braking; 2 - reversing the propeller 375 min⁻¹; 3 – ZUH1; 4 – ZUH2.

The device ZUH1 shows better effectiveness than ZUH2. The head reach in comparison with the reversed propeller braking (106 m = 11.86 x L_{WL}) is considerably shortened with the stern shield ZUH1 (46.0 m = 5.15 x L_{WL}) and ZUH2 (63.0 m = 7.0 x L_{WL}). When the model comes to a full stop with the shield lowered and the engine continuing to work forward at a steady speed of 375 min^{-1}, the model begins to move aft with increasing speed down to – 0.3 m/s. There is no need to stop and to reverse the engine. The engine is working all the time forward. Full course control is maintained during the whole process of braking and backing by means of ship's conventional rudder.

In order to get independent results of these two braking devices (ZUH1 + opening bulbous bow) tests have been ordered by the Gdansk University of Technology to the Ship Design and Research Centre (CTO) and they were carried out in the towing tank with a self propelled model of a 55000 TDW bulk carrier in scale 1:45.71 (length of the model L_{WL} = 4.618 m; speed of the model = 1.216 m/s equivalent to 16 knots of the ship). The results are shown in Tab. 3.

The above obtained results refer to the model only. Inertia braking distance was shortened by 44.4% with the use of bulb device (test No. 2). Crash stop of a full size ship according to trial report amounted to 1.980 m with a 80° change in course of ship. For the model it was accepted as 41 m (test No. 3). The effect of devices upon the braking distance are shown as results of tests Nos. 4, 5 & 6. The design of the ZUH1 should be improved because large part of the propeller stream was escaping above the shield.

The shield gives an improved manoeuvrability at slow speeds, where balance rudder is not efficient enough or in case of the loss of normal steering equipment for auxiliary steering, as was the case with S/T "Amoco Cadiz".

STEERING AND BRAKING DEVICE - - "DOERFFER'S RUDDER"

Stern shield gave impact to further studies and a new steering & braking device called "Doerffer's Rudder" was invented and developed (Fig. 6). It works at braking on the same basic principle as the stern shield. This rudder consists of a fixed forward part [1] and a swinging after part divided in the plane of symmetry into two blades [2 & 3], which can be swung open independently to on angle of –40° to +110° forming a shield behind the propeller. A vertical flap [4 & 5] is fitted on the trailing edge of each blade. These flaps could

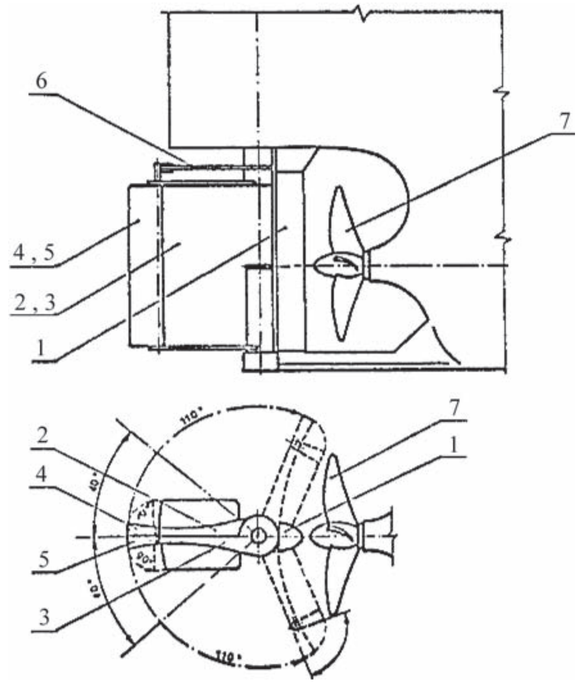

Fig. 6. Steering and braking device "Doerffer's Rudder" (SUH).

Tab. 3. Test results of braking the model of 55000 TDW.

Test No.	Description of test	Braking distance S [m]	Braking time T_h [s]	Distance decrease [%]	Summary force in stays [kG]	Propeller revolution [s^{-1}]
1	Inertia stopping	115.5	291	-	-	0
2	Inertia braking with bow device	64.2	176	44.4 [1]	-	0
3	Crash stop	41.0	82	-	-	17 forw. 12 revers.
4	Braking with ZUH1	31.6	72	23 [2]	3.8	17
5	Braking with ZUH1 + bow device	28.5	68	30.5 [2]	3.78	17
6	Crash stop + bow device	29.7	67	27.6 [2]	-	17 forw. 12 revers.

Note:
[1] - referred to braking distance in test No. 1
[2] - referred to braking distance in test No. 3

be swung open through an angle from 0° to 90°. As each blade has to be operated independently there are two rudder stocks fitted– an internal and an external one. Each rudder stock is activated by a separate steering engine through a total angle of 150°. The flaps could be activated by a fixed length stays [6] proportionally to the angle of blade opening or independently by hydraulic power hinges.

This type of rudder was fitted on the model of a "Panamax" ship and very thoroughly tested with regards to stopping and steering abilities. A very wide programme has been carried out in order to find optimum angles of opening the blades and flaps and the related braking and turning forces. The following parameters were recorded and the results are presented in Tab. 4 :

- time taken to stop the model [t] seconds
- distance travelled [s] meters
- speed astern [–V] m/sec after 240 seconds with propeller working forward.

Attention is to be drawn to the method of conducting the braking tests. On a stationary model the propeller is reversed to the required speed and only then it is accelerated to the equivalent service speed with the towing carriage. After this speed is reached, the towing carriage is disengaged and the braking process is commenced with "Doerffer's Rudder" the rudder is opened to required angle and the propeller is started forward. The model is accelerated to required speed and only then the towing carriage is disengaged. Thus in these tests no stopping and reversing the engine is simulated and thus the results are better than they would have been on a real ship. With "Doerffer's Rudder" this manoeuvre is very much shorter and once the opening procedure is started the braking process starts right away.

Tab. 4. *Measured test parameters.*

Opening of blades [°]	Opening of flaps [°]	Time taken to stop [s]	Distance travelled		Speed astern after 240 sec.
			S [m]	$N = s/L_{WL}$	
30	0	-	-	-	-
	30	-	-	-	-
	60	-	-	-	-
60	90	-	-	-	-
	0	-	-	-	-
	30	146	68	7.6	0.20
	60	97	58	6.3	0.35
90	90	115	67	7.5	0.40
	0	92	55	6.1	0.55
	30	63	43	4.8	0.60
	60	77	42	4.7	0.64
	90	90	52	5.8	0.58
100	60	90	47	5.2	0.50
103 110	30	76	42	4.7	0.65
	0	68	44	4.9	0.72
	30	90	50	5.6	0.58
	60	100	51	5.7	0.50

The best results are obtained with blades opened to 90° and flaps opened to 30° and 90°. Increasing the angles beyond these figures is not necessary, because it might complicate full size design. The possibility of obtaining astern speed with propeller running forward is a very positive feature of this device. All the speeds from top speed forward to top speed aft could be obtained by means of opening the blades (Fig. 7). Zero or near zero speeds could be obtained by opening the blades and flaps to angles shown in Table 5. Although the propeller is working at top revolutions the model remains stationary.

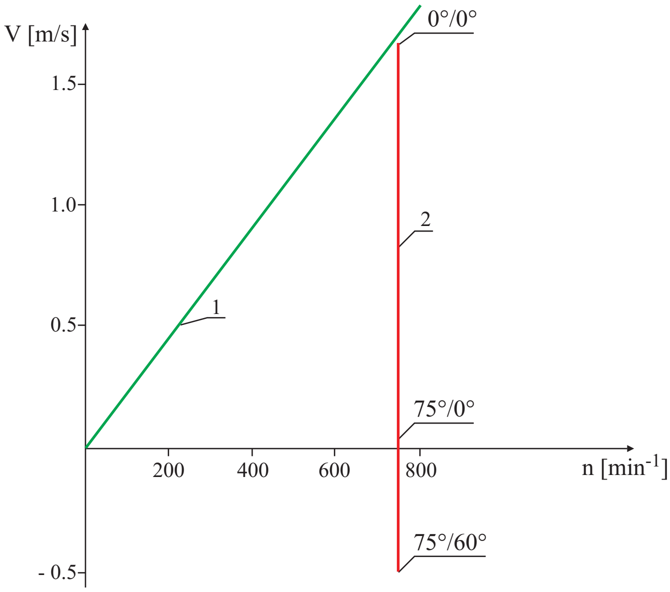

Fig. 7. *Speed of ship versus revolutions forward;* ***1*** *– speed with rudder blocked;* ***2*** *– speed with rudder opening at steady 750 min^{-1} forward.*

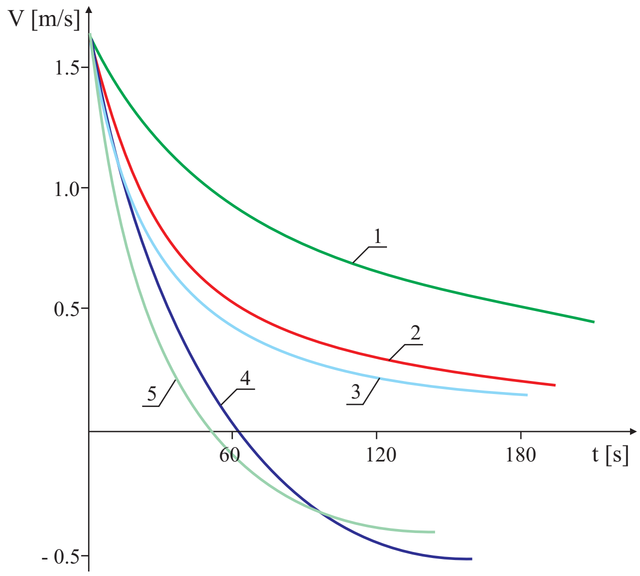

Fig. 8. *Speed versus braking time.* ***1*** *– inertia braking;* ***2*** *– DUH with 50° opening;* ***3*** *– DUH with 110° opening;* ***4*** *– SUH with 90°/30°;* ***5*** *- DUH 70° + SUH 90°/70°.*

Tab. 5. *Angles of blades and flaps opening for zero speeds.*

Angle of blade opening [°]	Angle of flap opening [°]	Speed of model at 750 min^{-1} [m/s]
75	0	0.00
45	60	- 0.04
45	90	+ 0.07

In the towing tank of 12.0 meters width this model (9.2 meters long) has shown excellent manoeuvring abilities carrying out comfortably pullout test and a 180° turn at a speed of 0.6 m/sec. The result of braking the model with "Doerffer's Rudder" only opened to an angle 90°/30° brought the model to a full stop the head reach $s = 4.8 \times L_{WL}$ is shown on Fig. 8 & 9 by curve [4]. When at the beginning of braking operation the bulbous bow is opened simultaneously to 70°, the result is shown by curve [5]. The head reach is reduced to s = 3.2 x L_{WL}. This result compared with inertia braking [1] and with braking by means of reversing the propeller about 12 x L_{WL} is astonishingly good. This means shortening the stopping distance by 60% and when DUH1 is added, by 77.15% with full course control and no side transfer.

The model was showing exceptional manoeuvring abilities. The model managed to manoeuvre out of the avanport of the model tank by its own means (Fig. 10) and to enter the model tank. From position [1] it moved to position [2 & 3] and then swung moving slowly forward to position [4], from which it sailed into open area of model tank.

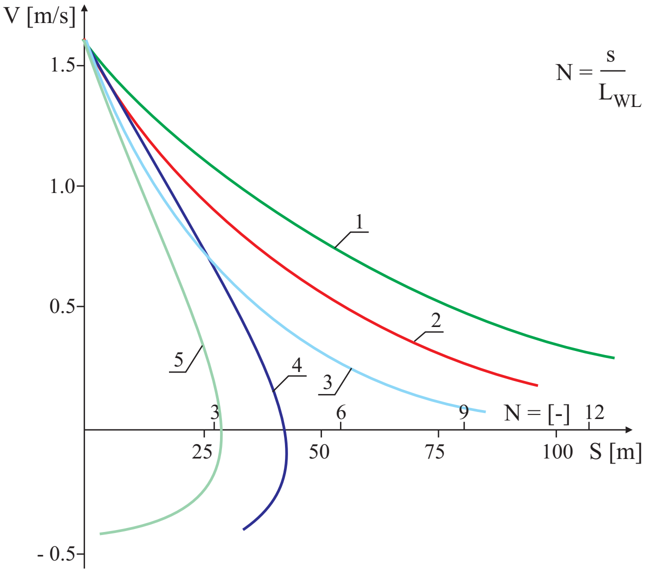

Fig. 9. *Speed versus distance travelled.*

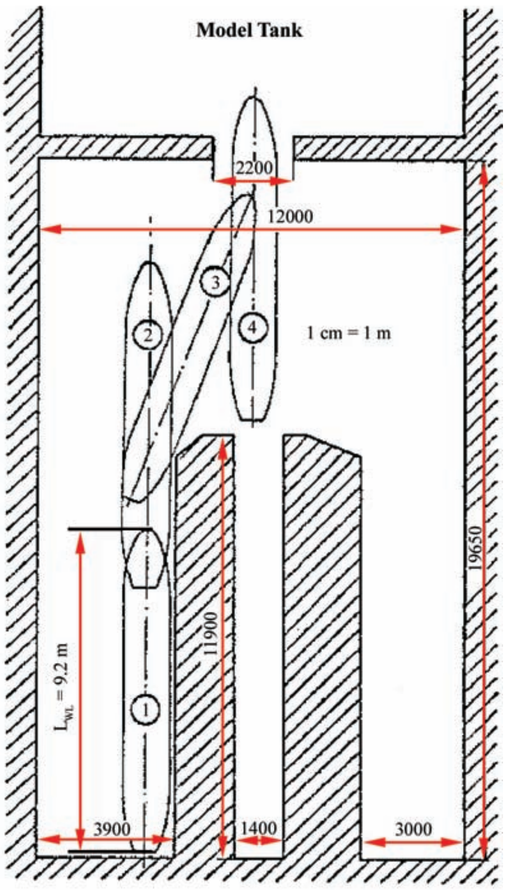

Fig. 10. *Panamax model manoeuvring in avanport of model tank.*

WAKE PRESSURE EQUALISING DEVICE

It is a well known fact, that the wake behind the ship in the area of propeller disc has different pressures and speeds, originating the vibrations and lowering the efficiency of the propeller. In order to prevent this a device has been invented (Fig. 11), which consists of two water intakes at the bilges [1] joining into one duct [2], supplying water to a pump of 98 mm diameter [3] accelerating this water and delivering it through the slots in upper part of the stern frame [4] into the area of decreased water pressure and speed. The pump has been designed for n = 1.125 min^{-1}, the speed of outflow stream was is 1.14 m/s and output of 8.6 l/s.

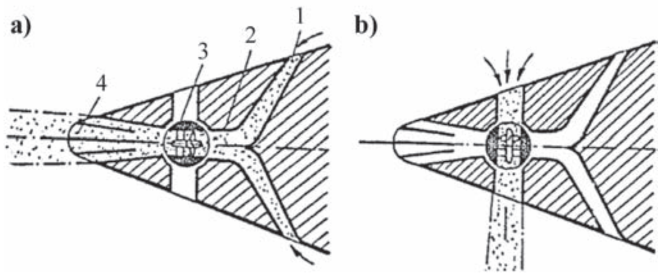

Fig.11. *Wake pressure equalising device (RUS).*
a) *- position of equalising and emergency propulsion;*
b) *– position of stern side thruster.*

The model has been tested with various speeds of the pump n = 450; 900; 1,350 and 1,800 min^{-1}. The measurements of outflow speeds were taken over an arc of ± 40° at V = 0 as well as for V = 1.63 m/s (Fig. 12).

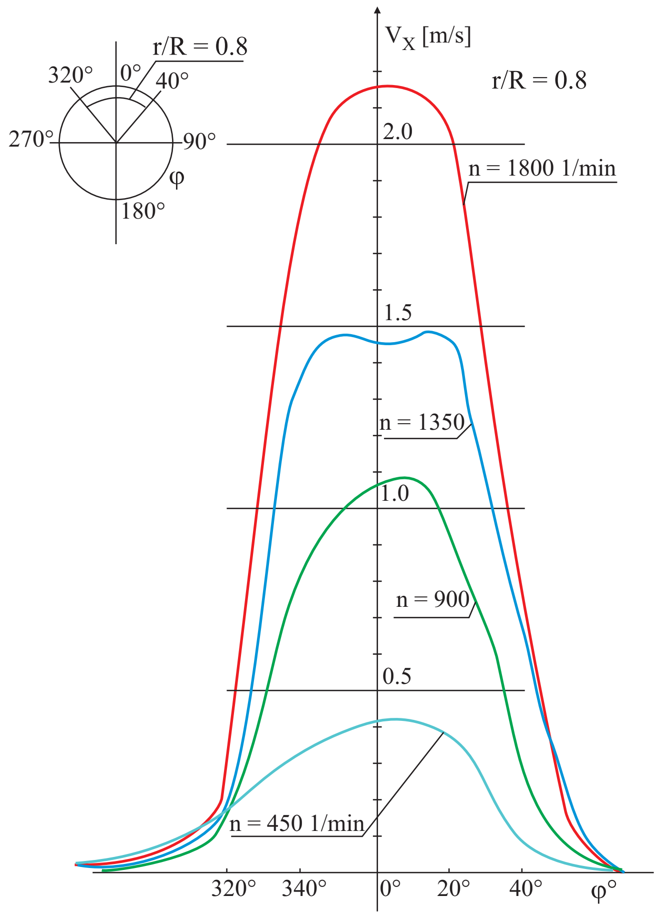

Fig. 12. *Outflow speeds Vx at a model zero over an arc ± 40° at different pump revolutions.*

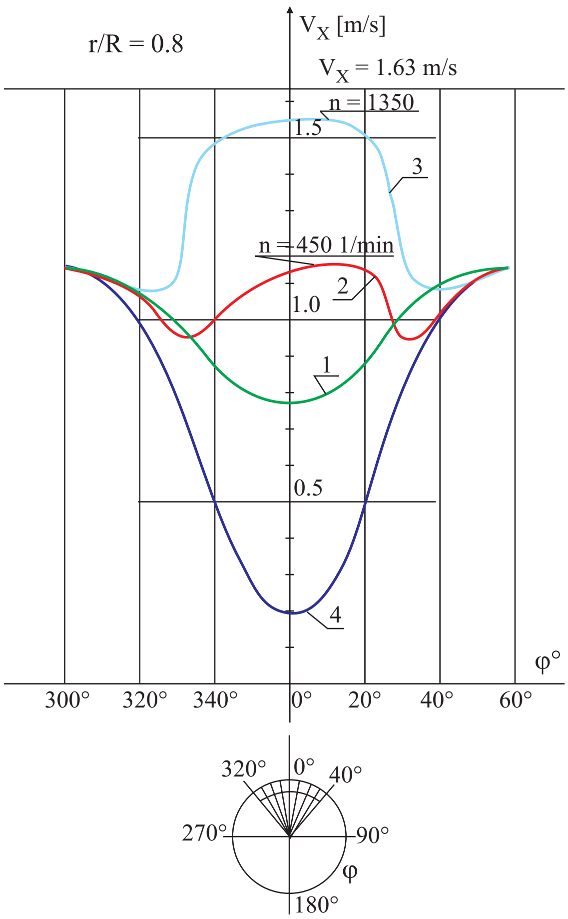

Fig. 13. *Outflow speed Vx at model speed 1.63 m/s over an arc ± 40°.*
1 *– pump stopped;* ***2*** *– pump at 900 min^{-1};* ***3*** *– pump at 1350 min^{-1};*
4 *– extremely bad design of stern end.*

The speed of water outflow V was measured over an arc ±40° at model speed 1.63 m/s (Fig. 13). Curve [1] shows the speed of water behind the well designed stern frame, curve [2] when the pump is working at 900 min^{-1} and [3] at 1.350 min^{-1}. Curve [4] shows the speed V at the extremely bad design of stern end.

As the pump is housed in a cylindrical casing it can be turned by 90° and used as a stern side thruster. This device could be used as an emergency drive in case of the failure of main propulsive machinery. In this case the pump should be driven by independent diesel generator. In order to take full advantage of this mode of emergency drive, it is necessary to have a free revolving fixed blade propeller or a variable pitch propeller, where the blades could be placed in a fore & aft direction.

CONCLUDING REMARKS

As the results of the tests with "Doerffer's Rudder", carried out in the cavitation tunnel and with models in the towing tank, have shown great merits of this device, it was decided to implement this device on a full size ship and to prove its applicability in real working conditions of a ship. Results of these trials are presented in part II of the paper titled "Doerffer's Rudder" – experience learnt from tests carried out on real ships".

BIBLIOGRAPHY

1. Doerffer J. (1986): *"Doerffer's Rudder" – a new development of a ship rudder*. Gdansk University of Technology. Ship Research Institute
2. Kalicinski J., Lech R. (1992): *Results of model tests of ship "Hollandia" with opening rudder* (in Polish). Ship Design and Research Centre
3. Kanar J., Czapiewski S. (1988): *Results of model tests with opening rudders* (in Polish). Ship Design & Research Centre
4. Koronowicz T., Centkowski J. (1978): *Identification experiments of stern braking shields* (in Polish). Gdansk University of Technology; Ship Research Institute
5. Koronowicz T., Jaworski S., Koronowicz J. (1978): *Identification experiments in cavitation tunnel of opening rudder as braking device* (in Polish). Gdansk University of Technology; Ship Research Institute
6. Lech R, Szponar K. (1978): *Comparative model tests of ship braking devices [opening bow and stern shield ZUH1]* (in Polish). Ship Design & Research Centre.

"Doerffer's Rudder" on mt. "Kolen".