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High-Performance Rudders—with Particular Reference to the Schilling Rudder

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The evolution of the rudder as a means of steering or maneuvering ships has not kept up with other progress in ship machinery and propulsion systems. During the past decade, however, several significant advances in ship maneuvering have been made based on the principle of diverting the propulsive thrust rather than simply steering the hull. One of these innovations is the Schilling rudder, which offers, at a relatively economical cost, greatly improved maneuverability even at very slow speeds. The Schilling rudder can be rotated 75 deg to either side without stalling, which provides stern thrust capability to the ship as the main engine thrust can be diverted at an angle of 90 deg to the hull. A twin Schilling Rudder system, with independently controllable rudders, has the additional features of allowing vectored reversal of ahead thrust, eliminating the need for a reversing gear or controllable-pitch propeller, and, when coupled with a suitable bow thrust device, can even provide a level of dynamic positioning capability to the ship. Both the single and double Schilling rudder systems have now been proven in service and their applicability extended to most types of vessels with no limit on size.

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Introduction

AT WHAT POINT during the history of civilization man first floated on a raft and made his way across the water in a chosen direction by paddling or rowing is lost in the mists of antiquity. But, certainly, manual oar-power preceded sail and the use of an oar for steering persisted for many centuries even after the advent of sail. The steering oar, apparently, was normally located on the right-hand side of the ship and hence Starboard, which is a derivation of the Old English words "steor" (steering) and "bord" (ship's side).

From the time of the first ships or floating platforms, about 4000 B.C. as far as we know, and throughout the intense development periods of the Greek and Roman Empires there were no real innovations in ship steering until the age of the great explorers, during the 15th century A.D., when the steering oar was superceded by a hinged rudder operated by a tiller. As sail design and sailmaking technology improved, the hinged rudder became smaller and a good ship was trimmed for a given course by adjustment of the various sails. Hulls became finer for extra speed and, in the heyday of the clipper ships, the rudder merged into the hull design to offer the minimum resistance.

As happened with the steering oar, this rudimentary rudder design persisted when sail gave way to power at the start of the 19th century, and it was common to see a centerline rudder even when a multi-screw configuration was used. It was acceptable practice that, on nearing port, a number of tugs, each operated by independent paddle wheels, nuzzled a ship into harbor with her engines shut down.

The rudders installed on the large 19th century steam-powered vessels were limited in their performance because of the great force required to attain the larger rudder angles necessary for effective maneuvering. To attain rudder angles of 30 deg in heavy seas, it was often necessary for the entire crew, sometimes approaching 100 men, to man the wheels and the special tackle fitted for the purpose. The development of the balanced rudder alleviated this problem and allowed rudder angles of 35 to 45 deg to be reached. The rudder still performed, however, in very much the same manner as its forebears.

Many brave attempts to improve the maneuverability of propeller driven vessels were made during the 19th and early 20th centuries including the introduction of the hinged flap rudder in 1881, Fig. 1. The hinged flap at the aft end of the rudder blade is arranged, through a mechanical linkage, to turn through double the angle of the main rudder blade. This allows a component of transverse thrust which provides a greater turning capability than that of conventional rudders without the flap. The unavailability, at the time, of suitable materials and the problems and lack of reliability associated with the relatively complex mechanisms necessary to operate them prevented flap rudders from becoming workable realities until fairly recently. A further enhancement of the flap rudder is the addition of an independently rotating cylinder at the leading edge which is said to improve the performance of either flap or conventional rudders by allowing larger rudder angles before flow separation occurs. Although the flap rudder and its variations have not been popular in the United States, it has been used extensively in Europe and is often the basis for comparison of performance with other types of rudders as will be evident later in this paper.

A ship's steering revolution

The idea that a powered ship must have a rudder activated by the passage of the hull through the water still persists. Only since about 1975 has it been appreciated that what a vessel really requires is a propeller slipstream controller or diverter, not a "ship's rudder" or "steering oar" at all. The steering effect is then no longer dependent on ship speed, but on how the thrust of the ship's propeller, or other propulsion device, is controlled.

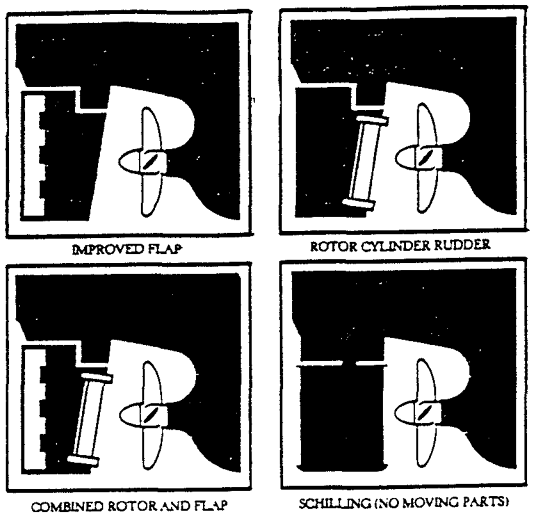


Fig. 1 Rudder types

As part of the ship's steering revolution, the paddle wheel was displaced by rotating vertical blades which could be feathered to provide thrust in any direction, the cycloidal propeller system. An "active" rudder was developed, with a small independently driven propeller mounted on the rudder itself. A propeller on an extended pillar which could be rotated through 360 deg, the so-called "Z"-drive system, and similar azimuthing propellers, some retractable into the hull, were introduced. Water jet propulsion systems, with the capability of altering the direction of the thrust to steer the vessel, have been used on some small craft. Multiple rudder ducted propeller systems and steering nozzles have found application on tugs and towboats. Many other innovative systems have also been proposed and, in some cases, applied aboard ship. All of these "revolutionary" systems improved the maneuverability of the vessel and were accepted by shipowners to varying degrees. They are, however, generally complicated and expensive and in many cases limited to new construction or to certain types or sizes of ships. They are also often prone to contact damage, particularly when operating in harbors or rivers where large amounts of debris are present or when operating in ice.

Transverse tunnel thrusters were introduced during the second half of this century and have been popular and successful, particularly on modern Great Lakes self-unloaders and certain workboats and river craft. Thrusters are expensive, especially when retrofitted to existing vessels, and are limited in their usefulness essentially to when the ship is not moving or moving at very low speed. They are also best suited to larger vessels, because of the space required within the hull.

Karl Schilling used the idea of controlling the slipstream to develop a design for a high-performance rudder, which produced a remarkable improvement in the maneuverability of Rhine River craft. Since 1975, when it was first fitted to a seagoing vessel, the Schilling concept has found an ever-increasing potential for shipboard applications—a potential not only among smaller inland waterways craft, but also encompassing seagoing ships, particularly coasters and Great Lakes type self-unloaders which need to be more "handy" and which require greater maneuverability than is available from a standard single rudder and propeller. Bow thrusters, for the larger vessels, and various types of specialized rudder propellers and steering nozzles have helped fill this need, but are not the complete solution.

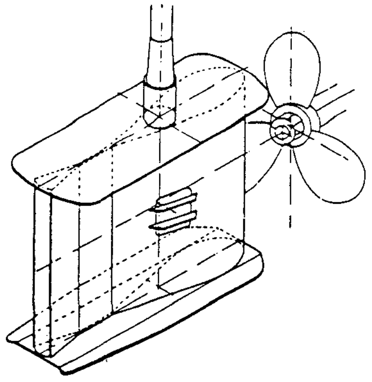
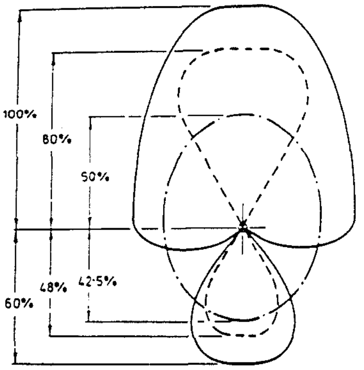


Fig. 2 The Schilling rudder



The original Schilling rudder design was based on a chord length of 1.3 or more propeller diameters, which required a larger than normal stern aperture. Recent positive experience with rudders down to one-half a propeller diameter in length, however, has made the Schilling rudder suitable for retrofit in most instances. The single rudder design is known as the Mono-Vec™ rudder.

Following the success of the single Schilling rudder, a design with twin rudders was developed. By moving the rudders in unison, the single Schilling maneuverability is retained, but by moving them independently the output of the propeller can be vectored and its thrust controlled over 360 deg. This results in an excellent slipstream controller and diverter. The concept works equally well if the propeller is shrouded in a nozzle. A further development is a joystick control to give the necessary positions of each rudder quite simply. The package of twin rudders and control gear is known as the Vec-Twin™ System.

Steering gear manufacturers have traditionally produced a 2 × 35 deg and 2 × 45 deg gears. The Schilling system makes use of 2 × 75 deg. This new requirement was first satisfied by using a hydraulic rotary actuator. Now most steering gear manufacturers are pleased to offer steering gears of both the rotary actuator and the more conventional ram type which can attain the greater angles. In many cases, it is possible and cost effective to adapt the original steering gear to deliver the larger angles when Schilling rudders are fitted on existing ships.

This paper describes primarily the Schilling rudder both in its single and double configurations. It is the authors' opinion that the Schilling concept is a most suitable method for improving the maneuverability of all types of ships. The arguments used and conclusions drawn arise from their experience with the Schilling rudder. Many of them can be applied as well to other devices which use control of the direction of the propulsive force to maneuver the vessel.

The need to continually improve the maneuvering capability of ships at an economical cost has been recognized by Panel H-10 of the SNAME Ship Hydrodynamics Committee, which is concerned with ship controllability and which is currently preparing a new *Maneuvering Handbook* which is due for publication shortly. A Panel H-10 paper entitled "Design and Verification for Adequate Ship Maneuverability" was published in SNAME *Transactions*, Vol. 91, 1983, pp. 351–401. This paper provides an extensive review and analysis of the needed improvements, the existing regulatory controls and the methods of testing for and evaluating manuevering characteristics and capability. It also contains an extensive reference list of other papers on the subject.

The Schilling rudder

The patented design of the Schilling rudder comprises a robust one-piece balanced rudder, Fig. 2, which incorporates slipstream guide plates and a special hydrodynamic profile which allows, to an acceptable degree, extreme rudder angles without stalling.

Viewed in plan, the Schilling rudder is fish shaped with a fat section at about 20 percent chord, a taper to a thin waist and a wider tail. The stock is positioned at about 40 percent of the chord aft of the leading edge and wide plates at the top and bottom of the rudder control flow over the edges of the profile.

The secret of this rudder is that rudder angles up to 75 deg may be used without stalling. As a result, the rudder profile can deflect the propeller slipstream to more than 90 deg so that a side thrust is obtained at the stern with little or no forward component. This means that a coaster, for example, equipped with a single Schilling rudder can spin on its axis. By fitting a tunnel thruster forward, the vessel can be forced sidewards against tide and wind. There is no need to fit a stern thruster if a Schilling rudder is used. For a coaster, which spends most of its time in open water but must operate agilely for limited periods in confined channels, fitting the Schilling rudder alone, rather than more elaborate maneuvering systems, represents a good compromise between cost and effectiveness. The coursekeeping ability of Schilling rudder vessels is greatly improved. They appear almost to run on a train track, the heading is so well maintained.

Effective steerage is maintained at lower speeds with a Schilling rudder, and is not significantly impaired by shallow water. This performance is of considerable value for ships traveling in rivers, canals and other restricted waterways, when the greater effectiveness of the Schilling rudder at low speeds reduces ship to ship interaction or bank suction. It is also of value when the vessel must maneuver at very slow speeds for special activities, such as oil spill recovery or salvage operations.

The first vessel to be retrofitted with the Schilling rudder in the United Kingdom, where the use of the rudder on larger vessels was pioneered, was the Charrington tank barge *Charcrest*. Since then, more than 150 vessels of various sizes and services have been fitted with Schilling rudders and the device is now being accepted for increasingly larger ships. A current list of seagoing vessels fitted with the Schilling rudder is contained in Appendix 1.

Retrofitting the Schilling rudder to existing vessels is generally possible. Most types of stern arrangements can be accommodated as the design of the Schilling rudder can be adapted with little sacrifice in performance. It makes no difference to a Schilling rudder whether a propeller is shrouded in a nozzle or not as the whole slipstream is, in each case, diverted to achieve the same maneuverability.

The basic simplicity of the single or double Schilling rudders allows either design to be a viable possibility for any size ship. Already proposals for vessels of over 100 000 tons have been accepted both by classification societies and well-known shipowners, with orders imminent.

Relative performance of high-lift rudders

Figure 3 gives a comparison of lift coefficients at different rudder angles of a Schilling rudder, a moving flap rudder and a conventional National Advisory Committee for Aeronautics (NACA) section rudder. In the ahead mode, a flap rudder initially has the highest lift coefficient, but coupled with a low lift-drag coefficient ratio. Beyond 30 deg, the Schilling rudder gives much greater turning moment than either of the others, both of which stall beyond 40 deg.

In the astern mode, the Schilling gives greater thrust than a NACA rudder at all angles. The flap rudder, owing to its configuration, is greatly inferior even to a NACA rudder in this mode.

Figure 4 shows the turning performance, based on authoritative sources, of a ship with several types of rudders. A detailed description of the turning capabilities of ships fitted with Schilling rudders is contained in Appendix 2.

The beneficial effect of the Schilling rudder on course stability has been illustrated by comparative model tests together with conventional rudders. The results of these tests are presented in Appendix 3.

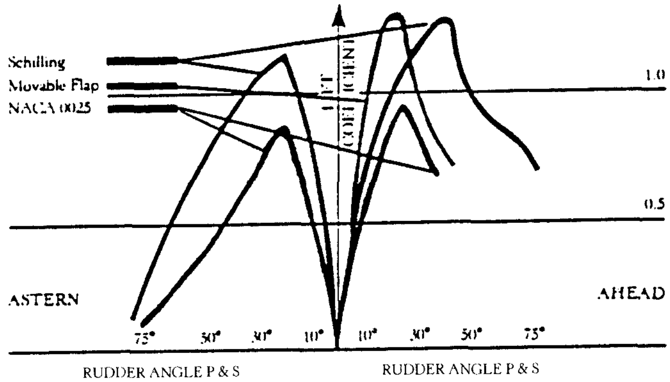
The relative average drag of the rudders, under various conditions of operation, is difficult to evaluate, but in all cases it is very small in relation to total hull resistance.

A Schilling rudder, to give full transverse thrust, is greater in area than an equivalent NACA rudder and the surface area of the end plates produces some additional skin friction. The Schilling rudder, however, due to its high lift coefficient and its end plates, has the beneficial effect of straightening the propeller slipstream, which effectively strikes it at an angle even with the rudder in the fore-and-aft position. This, in fact, produces some positive forward thrust on the rudder, which in practice appears to balance the extra surface area drag of the Schilling.

Since the body of a moving flap rudder stalls at essentially the same angle as a NACA rudder, shortly after which the acute angularity of the flap actually detracts from its performance, only normal rudder angles and associated steering gears giving about 35 to 45 deg each way are used. A Schilling rudder is, however, effective up to rudder angles of 75 deg each way, allowing it to provide 90-deg thrust to the stern. This larger angular range can be easily achieved with either a double ram type steering gear or a hydraulic rotary vane type steering gear with very little additional cost. The good balance of the Schilling rudder requires no greater operating torque at any angle than a conventional rudder. It is also sometimes possible to adapt existing steering gears to provide the larger angular capability to retrofitted Schilling rudders.

A comparison of the design of the two rudders makes it clear that the Schilling is much simpler in construction and less expensive than the flap type and is far less vulnerable to damage from grounding, side impact, ice or heavy cross seas. The complete absence of moving parts—compared with the multiple hinge bearings, operating gear, and the sliding cylinder link of the flap rudder—clearly gives the Schilling far lower maintenance cost and improved reliability.

The Schilling rudder, because of its simple design with no moving parts other than the rudder blade itself, is no more vulnerable to damage from ice or other debris than a conventional rudder. The Schilling rudder has been installed on many vessels which normally operate in ice with no problems reported. The rudder can be designed and fabricated to meet the various ice class specifications of the regulatory agencies and can be built with special scantlings for severe duty applications.



	SCHILLING RUDDER	CONVENTIONAL RUDDER (NACA 0025)
Velocity	2.0 m/s	2.0 m/s
Area	0.103 m^2	0.125 m^2
Taper	1.0	1.25
Aspect Ratio	0.853	0.98
Reynolds No	0.604 x 10^6	0.619 x 10^6

Test Results by HSVA Hamburg

Fig. 3 Comparison of lift coefficients

Guidelines for users of Schilling rudders

A designer or owner considering specifying a Schilling rudder for the first time is no longer branching out into the unknown. The Schilling design makes use of several well-tried principles and combines them to permit a unique operating angle of up to 75 deg, which is the basis of the patented design. The rudder has been well proven at sea for over ten years. The design is extremely strong and has shown itself capable of withstanding considerable impact without damage. The need for a stern thruster is eliminated as a Schilling rudder at full helm is equivalent to a stern thruster of the order of 70 percent of main engine power.

The high-lift section of the Schilling design, which is responsible for the extreme maneuverability, also combines with the

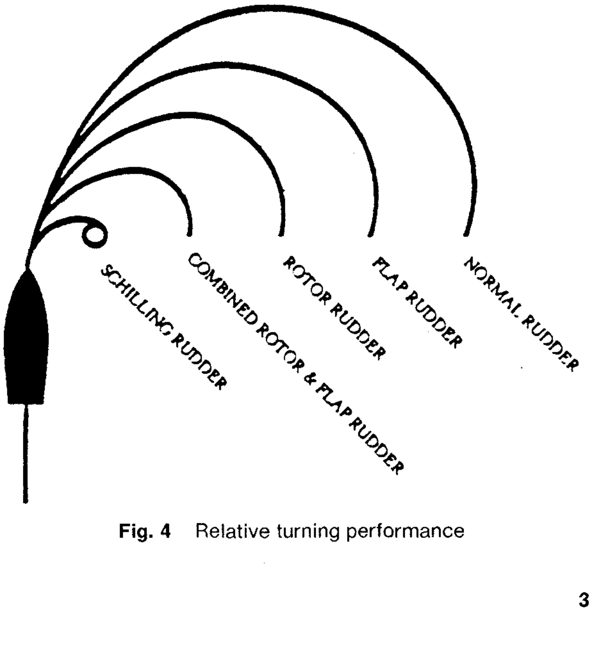


Fig. 4 Relative turning performance

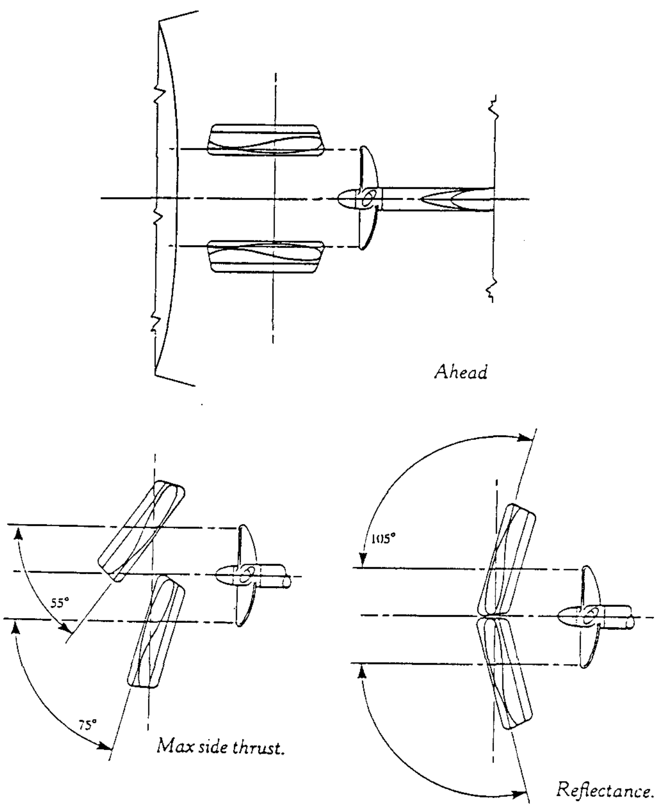


Fig. 5 The twin Schilling rudder

slipstream to augment the thrust to some extent and, as a result, there is no loss in speed compared with a conventional rudder. The rudder is suitable for any size of vessel.

Detailed design guidance is available for specific Schilling rudder projects, but for general purposes the following points should be noted:

1. The steering gear selected should be capable of not less than 140 deg travel, 70 deg port and 70 deg starboard.
2. The balance of a single Schilling rudder is usually 40 percent.
3. A chord length of up to 1.2 × propeller diameter may be used for maximum maneuverability.
4. The height of the Schilling is usually less than traditional design and approximates the propeller diameter.
5. The distance between the leading edge of the rudder and the trailing edge of the screw is usually not less than 0.2 × propeller diameter.
6. For general guidance, there should be a distance of 0.75 × propeller diameter between the stock centerline (after perpendicular) and the trailing edge of the propeller. A similar distance between the stock centerline and the transom should ensure that the trailing edge of the rudder does not protrude aft.
7. It is always good practice to ensure minimum clearance between the underside of the hull and the top of the rudder to prevent lateral wash over the rudder blade, and to aid course-keeping. A fixed skeg may be used to reduce this clearance.
8. The Schilling design is most effective in extracting the kinetic energy of the slipstream to reduce propeller-induced noise. However, it is good practice to ensure that the after lines allow a good flow into the propeller to prevent cavitation due to tip vorticing.
9. The strength of the Schilling rudder allows the lower pintle to be omitted if so desired.
10. If the extreme maneuverability of a fully developed Schilling rudder is not required, a smaller version may be used as size-for-size the Schilling section will generate up to 30 percent more lift than the flap or other active rudder designs. Rudders of reduced chord length equalling only 0.55 propeller diameters have proved effective.

The twin Schilling system

Until recently, extreme maneuverability for ships has only been achieved by complicated systems at the expense of propulsion efficiency. Rotating azimuth propellers and cycloidal propeller systems achieve significantly less efficiency than a conventional propeller system.

The twin Schilling rudder system with coordinated joystick control delivers an extremely high level of maneuverability using a fixed-pitch propeller which has an efficiency advantage over a controllable-pitch (CP) unit.

The joystick-controlled twin independent Schilling rudders eliminate the need for reversing the rotation of the engine or propeller pitch, which simplifies the installation. This concept, for reversing the thrust using two independently controlled Schilling rudders, has already been accepted and approved by several regulatory agencies, including Lloyd's. There is certainly a role for this twin-rudder system on virtually any vessel when economies in both construction and operational maintenance are considerations.

Figure 5 indicates the various maneuvering modes of the twin independent Schilling system, which is controlled reliably and simply by a single joystick.

There are numerous, and sometimes unexpected, additional benefits to the fitting of this innovative steering system:

- At the design stage, because the need for reversing gear is eliminated, there are tangible reductions in first cost of the vessel even for a simple ship concept. For a more sophisticated ship where the need for CP propellers and other maneuvering devices is also eliminated, the cost savings are particularly impressive.
- In addition to improved maneuvering capability, the twin Schilling rudder system also offers improved stopping capability over that generated by reversing the rotation of the propellers. Astern thrust equal to about 35 percent of ahead bollard pull is available due to the reversal of the slipstream. The forces generated by the rudders when stopping the ship can also be controlled to swing the stern in any direction, yielding superior astern steering control than that available with a reversing propeller and normal rudder.
- Time spent maneuvering is safely reduced with far less wear and tear on the main engines. Because the ahead motion of the ship is fully controllable by simply angling the rudders at all powers, it is, therefore, never necessary to run the engine at very low loads, which poses a problem when using heavy fuel for diesels. Operating at a constant engine loading even while maneuvering has the added benefit of lower fuel usage.
- By "differentially" angling the two rudders, using the single joystick, the ship's stern can be pushed in any direction or held stationary without reversing or varying the propeller speed. Even with the engine running at maximum rpm, a tow may be taken up very gently with full power readily available by altering rudder angles only.
- It can be seen that to attain a certain degree of dynamic positioning capability with twin Schilling rudders, it is only necessary to introduce a transverse bow thruster to a ship with a single fixed-pitch screw constantly rotating ahead. As this concept is much simpler than any other dynamic positioning (DP) system, the interfacing to any DP indicator system or computer control is also simpler.
- The twin Schilling rudder system incorporates two separate steering gears and is, therefore, able to satisfy Internation-

al Maritime Organization (IMO) recommendations for steering gear redundancy, which is a requirement for large tank vessels.

- When in the hovering mode (that is, maneuvering on the spot), there is only outward radial flow from the propeller, which lessens the risk of fouling trailing ropes.

Seagoing experience since April 1984 with the liquefied petroleum gas (LPG) carrier *Tarihiko*, owned and operated by the Shipping Corporation of New Zealand for Liquigas, Ltd., has shown the VecTwin System to be a reliable seagoing practicality. The vessel has performed as indicated in the model tests where tight, "on the spot," turning circles at 12 knots were achieved and the predicted stopping distance with the rudders at the maximum angle, "barn door," position was 1¼ ship lengths.

The design is appropriate to any size of ship up to approximately 20 knots although, if fitted with an interlock to limit rudder angles at high powers, faster ships could be considered. Twin Schilling rudders may be used with a ducted propeller to form a very compact installation, the rudder blades being only about 0.8 × the propeller diameter. The fixed duct gives the optimum improved propulsion efficiency, and the linked twin rudder gives the same ship turning performance and requires relatively low operating torque from the steering gear. The thrust vector diagram of the twin Schilling rudder with a fixed nozzle shows the remarkable steering performance of this combination, Fig. 6.

There is positive advantage for the ship designer and the shipowner to consider the twin Schilling rudder system for most types of seagoing and inland waterways vessels on the bases of maneuverability, simplicity, economy and performance.

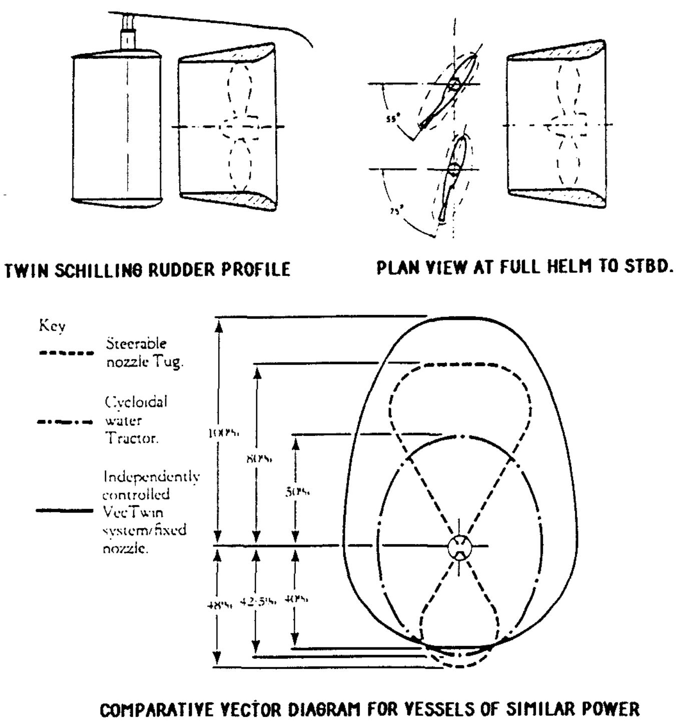


Fig. 6 Twin Schilling rudder with fixed nozzle

Trial results

In Appendix 4 some of the results recorded during the trials of the MV *Oresund* are shown. The *Oresund* was recently delivered by Norway's Moss Verft yard to the Swedish State Railways. She will operate between Helsingborg, Sweden and Copenhagen, Denmark as part of the Danlink ferry system linking Sweden, Denmark and West Germany. Speed and maneuverability are essential in order that the schedule of five round trips per day be maintained. Port turnaround time is 35 minutes, during which 55 railcars must be unloaded and another 55 loaded.

MV *Oresund* is 185 m (607 ft) long with a service speed of 19.5 knots and is fitted with two propellers and two single Schilling rudders. Although the rudders were slightly smaller than standard, excellent results were attained on trials. From page 12 of the trial report, Appendix 4, it can be noted that, using the rudders at only half speed for emergency stop, the advance was 440 m (1443 ft) with very small transfer compared with a half ahead, full stern advance of 490 m (1608 ft). The rudder stop also induced significantly less vibration.

With a twin Schilling rudder system the stopping distance would be even less and the vessel would stop in a straight line under full control and with very little vibration.

The *Oresund* travels astern for considerable distance when leaving Copenhagen harbor. In the astern mode the Schilling rudders have a lift about 25 percent greater than conventional rudders, giving a much greater degree of control. The starboard, full-ahead trial, page 10 of Appendix 4, was carried out at a 35-deg rudder angle at the owner's request. In fact there is no restriction on the use of the rudder to the full 70 deg at any ship's speed. In general, the angle of heel is less with the Schilling rudder than with conventional rudders due to the rapid drop in speed at wide angles.

The disappearing credibility gap

There is always a credibility gap to bridge until prospective users have experience with a new product. This is particularly true in the marine industry. It is always better if someone else has tried it first on a similar ship or in an engine room with the same propulsion system and auxiliaries.

Because of the unexpected performance advantages of the Schilling rudder, ship designers and owners often cannot believe that such a simple, tough design can outperform the more complicated and more expensive hardware which tradition has, up to now, dictated as necessary for enhanced maneuverability. Tradition in marine practice is hard to overcome, particularly in difficult economic times, and can prevent the introduction of change despite even a multitude of advantages. Had the Schilling design emerged as a practical application for larger vessels prior to 1975, before the continuing surplus of vessels of all types, the picture would almost certainly be far different. Nevertheless, penetration into the offshore vessel market, at least in Europe, has begun. Present newbuilding inquiries from dredging companies, coastal tanker and cargo vessel operators, and shipping companies which operate ferries and other craft requiring enhanced maneuverability indicate that Schilling rudders are now being regularly considered and specified.

Although progress has been made into the traditional cargo/bulk ship field and some fleets in Europe have standardized on the Schilling, vessels are still being specified with stern thrusters and conventional rudders or CP propellers when the specification of a single Schilling rudder would be both cost- and performance-effective.

As may be imagined, the credibility gap with the twin Schilling system is even wider than with the single system. Although the system's potential has been apparent from tank tests and radio-controlled models for some years, it was only in April of 1984 that the first VecTwin System ship completed trials, the MV *Tarihiko*. Aboard this 3370-dwt gas carrier, the twin system has performed reliably and it is apparent that this vessel has become the precursor of a ship concept which could prove to be, perhaps, the greatest breakthrough ever in ship propulsion and maneuverability. It has finally attracted the attention of ferry operators and others interested in the remarkable performance potentially available.

Following the successful introduction of MV *Tarihiko*, several other vessels including a roll-on/roll-off (RO/RO) ferry and an oil terminal service and spill control vessel have been successfully fitted with twin Schilling systems. A proposed 8000-dwt single-screw cement carrier has also specified the VecTwin System. This increased exposure will, it is hoped, help to close the credibility gap. Progress is being made in the development of the dynamic positioning capability of the twin Schilling system combined with a bow thruster. There may be an even wider credibility gap to close in this field in the near future as the cost saving potential is even greater.

There is evidence that minor design changes could be further incorporated, particularly to the twin Schilling system, to maximize the extraction of wasted energy. We know, however, from the original development work that progress takes time as innovations must first be proven in practice to provide the motivation and to attract the support to go on. The full impact of this technology on the marine industry is yet to be felt. It is hoped that the Schilling rudder concepts will shortly be recognized as the major breakthrough in ship propulsion technology that they surely represent.

Appendix 1

Schilling rudders fitted to seagoing vessels as of Sept. 1986

VESSEL NAME	TYPE OF VESSEL	DWT	YEAR BUILT	LENGTH B.P.(M)	SHAFT H.P.	PROP DIA.(M)
Charcrest	River Tanker		1976	59.8	620	1.98
St.Kearan	Tanker	730	1977	50	600	1.9
Militence	Cargoship	1408	1977	68	1000	2.0
Nascence	Cargoship	1408	1977	68	1000	2.0
London Miller	Cargoship	1391	1977	68	1000	2.0
Birkenhead Miller	Cargoship	1391	1977	68	1000	2.0
Blackheath	Tanker	1100	1978	72	1160	2.0
Bromley	Tanker	782	1979	57	780	1.8
Esso Plymouth	Tanker	2938	1980	66.5	2250	2.6
Urgence	Cargoship	1842	1980	81	999	2.0
Vibrence	Cargoship	1842	1980	81	999	2.0
Crescence	Cargoship	840	1981	48	468	1.6
Norbrit Faith	Cargoship	2300	1981	65	1350	2.5
Norbrit Hope	Cargoship	2300	1981	65	1350	2.5
Shell Seafarer	Tanker	3027	1981	74.5	3000	2.85
Shell Marketer	Tanker	3027	1981	74.5	3000	2.85
Shell Technician	Tanker	3027	1981	74.5	3000	2.85
St Oran	Heavy Lift Ro Ro	720	1981	50	685	1.8
Ballygarvey	Bulk carrier	2615	1982	72	2450	2.45
Ambience	Cargoship	800	1982	48	468	1.6
Stridence	Cargoship	1820	1982	81	999	2.0
Turbulence	Cargoship	1820	1982	81	999	2.0
Barrier	Tanker	615	1982	52	500	1.7
Ballygrainey	Bulk carrier	2615	1983	72	2450	2.45
Willonia	Cargoship	2420	1983	73	1267	2.85
Selectivity	Cargoship	2420	1983	73	1267	2.85
Pamela Everard	Cargoship	2420	1983	73	1267	2.85
River Tamar	Cargoship	840	1981	48	575	1.6
Piquence	Bulk carrier	1350	1979	68.64	1160	2.0
Quiescence	Bulk carrier	1350	1979	68.64	1160	2.0
Beckenham	Tanker	1050	1980	60.51	1160	2.0
Blackheath	Tanker	1050	1980	56.88	1160	2.0
Tarquence	Box Hold	800	1980	47.75	575	1.60
Brentwood	Tanker	1570	1980	66.34	1085	1.95
Union Mars	Bulk carrier	1395	1981	66.14	999	1.95
Union Venus	Bulk carrier	1395	1981	66.14	999	1.95
River Dart	Box Hold	800	1981	47.75	575	1.60
Union Pluto	Bulk carrier	1395	1981	66.14	999	1.95
Kirsten Frank	Cargoship	1630	1982	68.28	800	1.95
Edith M	Cargoship	1630	1982	68.28	800	1.95
Arktis Star	Cargoship	1630	1982	68.28	800	1.95
Kraka	Cargoship	1630	1982	68.28	800	1.95
Herborg	Cargoship	1630	1982	68.28	800	1.95
Arktis Moon	Cargoship	1630	1982	68.28	800	1.95
Karolina	Cargoship	1630	1982	68.28	800	1.95
Birth Boye	Cargoship	1630	1983	68.28	800	1.95
Hermod	Cargoship	1630	1983	68.28	800	1.95
Jette Dania	Cargoship	1600	1983	68.28	800	1.95
Karen Dania	Cargoship	1600	1983	68.28	800	1.95
Boisterence	Box hold	800	1983	47.75	575	1.60
Karin M	Cargoship	1630	1983	68.28	800	1.95
Lottelith	Cargoship	1630	1984	68.28	800	1.95
Panther	Cargoship	1053	1984	62.00	500	1.70
Tiger	Cargoship	1048	1984	62.00	500	1.70
Nadia J	Cargoship	1053	1984	62.00	500	1.70
Arktis Pearl	Cargoship	1730	1984	70.16	800	1.95
Arktis Sea	Cargoship	1730	1984	70.16	800	1.95
Jotun	Cargoship	1053	1984	62.00	500	1.70
Dansus	Cargoship	1043	1984	62.00	400	1.70
Union Emerald	Cargoship	985	1974	60.00	900	1.5
Union Gem	Cargoship	985	1976	60.00	900	1.5
Union Jupiter	Cargoship	985	1977	60.00	900	1.5
Union Pearl	Cargoship	985	1977	60.00	900	1.5
Union Saturn	Cargoship	985	1977	60.00	900	1.5
Gudbjartur	Trawler		1985	40.7	1750	2.9
Rosund	Trawler		1985	38.0	2000	3.1
Ocean Flower	Offshore		1985	55.0	2x1000	2.0
Swedish State RR	Rail/Car/Pass	6300	1986	178.9	2x9000	4.2
Remoy Viking	Seiner Viking		1985	45	1800	2.7
Ocean Star	Offshore Vessel		1986	52.9	2x1500	2.3
Andre Vagsholm†	Scalloper		1986	58.5	3500	3.8
Belard*	Ro Ro Ferry	5220	1985	96	4500	3.15
F.T. Everards†	Cargoship		1985	73	945kw	2.85
Union Titan	Cargoship		1985	82.8	1200	1.9
Union Moon	Cargoship		1986	82.8	1200	1.9
Union Sun	Cargoship			82.8	1200	1.9
Union Neptune	Cargoship			82.8	1200	1.9
Union Sapphire	Cargoship			82.8	1200	1.9
Union Topaz	Cargoship			82.8	1200	1.9
Tarihiko*	LPG Carrier	3370	1984	75	2500	3.0
Staines Moor*	Service Craft		1983	18.3	270	2x1120
Robalo	Ferry		1986	97	7200	3.5
Commander	Offshore		1986	63		2x2.35
Subsea	Support					
Tress Pioneer	Scalloper		1986	59	3264	3.9
Kronbas	Supply Tug	2300	1986	62	3520	2x2.75
Reynsatindur	Trawler	5345	1986	95	6000	3.6
Glutra	Ferry	400	1986	37	480	1.85
A/S Vikavaag	Longliner		1986	27.5	1000	2.4
Oddmund Myrbœ						
Flekkefjord Slip†	Trawler		1986	48	2500	3.5
Brœdr Aarsæther	Trawler		1986	48	3000	3.8
P/F Val Faroes	Trawler	2500	1986	52	4590	3.6
Matthew Flinders	Show Boat	485	1986	44	440	1.57
Leonard J. Cowley	Fisheries Protect.	500	1985	72	4400	2.8
Strand Senior	Seiner	1800	1986	49	1800	2.9
N. Z. Cement Hldgs*	Cement Carrier	9100	1987	110	6600	4.3
CHEVRON	Tanker	68000	1987	231	13000	6.4
CHEVRON	Tanker	68000	1987	231	13000	6.4
St. Ola	Ferry	701	1987	65.5		2x2.2
Shinhama Dock†	Cargo	1600	1987	66	1400	2.7
Hyundai†	Pass./Cont.	25000	1987	156	17850	6.4
Tito Yard†	Cargo		1987	52		2.0

* VecTwin™ Rudder System
† Building yard

Appendix 2: Turning circles

Definitions

Advance—The distance travelled by the vessel in the original direction of travel (usually measured when the vessel has altered course by 90 degrees).

Transfer—The distance at right angles to the original track through which the vessel has moved. The datum point for advance and transfer is usually the point at which the helm has been put hard over.

Turning capabilities

From a "ship at rest" situation, the Schilling rudder enables a vessel to rotate on the spot.

With a vessel underway, the turning circle with the helm hard over is not greatly affected by the speed of entry. On one vessel, recently, it was found that the track at a speed of entry of 15 knots was almost identical to the track at speeds of entry of 10 knots and 5 knots.

Due to the rapid rate of turn of a vessel with a Schilling rudder used at high angles, the speed through the water is rapidly reduced and the "advance" and "transfer" are very much less than for a vessel with any other type of rudder.

Typically, a 100-m (328 ft) vessel at a speed of entry of 16 knots would have turned through 90 deg after an "advance" of about 2.2 ship lengths and with a "transfer" of about 1 ship length.

At a speed of entry of 10 knots, the "advance" would be about 1.8 ship lengths and "transfer" 0.7 ship lengths.

This results in having the ability to cease "advancing" (that is, stop) by keeping on full power ahead and using the Schilling rudder to turn the vessel. The "advance" by that maneuver is usually about half of the distance required to stop the vessel by reversing the engine or CP propeller. Since a reversing propeller often causes the vessel to sheer wildly off course, the odd situation arises that often the "transfer" is reduced by using the Schilling rudder in this way.

With the twin rudder system, the "advance" after "clamshelling" the rudders is also about half of the usual stopping distance, but there is also the significant advantage that the vessel will, unaided, stop in a straight line.

While stopping, a ship can be easily steered by using the single joystick controller to swing the stern to port or starborad. Steering in this manner does not greatly affect the stopping distance. Ship safety can be greatly improved by the ability to maneuver in this way.

Very high rates of turn are attainable with tight turning circles. The rate of turn is dependent on the relationship between the mass of the ship and the power of the propulsion machinery. Typically, a 75-m (246 ft) vessel of 2000 tons displacement with 3000 hp (2237 kW) will turn at about 3 deg/sec in a circle of less than the ship's length. A 100 m (328 ft) vessel of 4000 tons displacement with 3000 hp (2237 kW) will turn at about 1.7 deg/sec in a circle of about one ship's length.

Appendix 3: Coursekeeping

Recent model tests on a shallow-draft, full form vessel of 110 000 tons displacement have clearly illustrated the significant beneficial effect of the single Schilling rudder on course stability. This advantage alone would often be sufficient to justify the fitting of a Schilling rather than a conventional rudder.

Rudder	Conventional	Large Conventional	Schilling
Area (m^2)	58	80	58
A	1.5 sec.	1.57 sec.	1.66 sec.
B	2.85 sec.	2.25 sec.	1.09 sec.
C	15°	10.7°	7.3°
D	as expected	as expected	no hysterisis

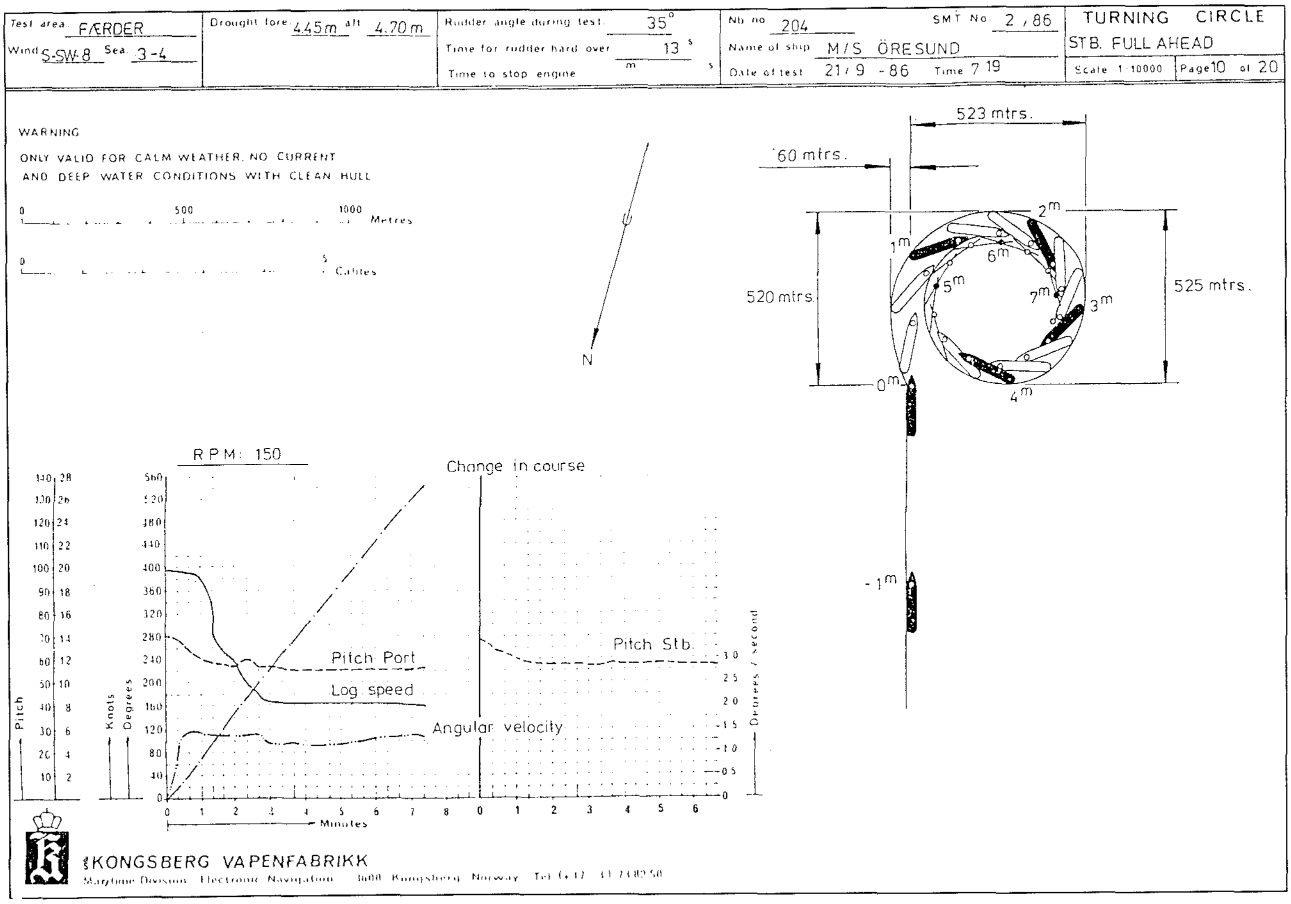
A. Initial turning time for a 10-deg/10-deg zigzag. Time in seconds taken for a 10-deg heading change with a 10-deg rudder angle.

B. Yaw checking time. 10-deg rudder angle to check 10-deg ship's head yaw.

C. Overshoot angle. 10-deg rudder for 10-deg ship's heading change.

D. Spiral hysterisis loop.

Appendix 4: Trial report excerpts—MV *Oresund*



(Continued)

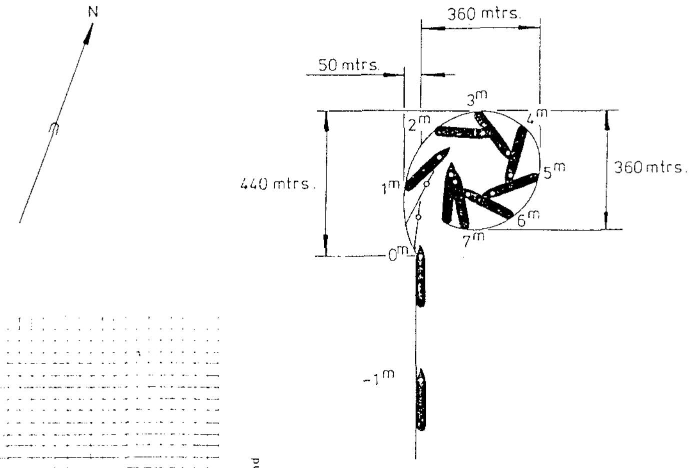
Test area: FÆRDER	Drought fore: 4.5m aft: 4.5m	Rudder angle during test: 70°	Nb no. 204 SMT No: 2 / 86	TURNING CIRCLE
Wind: S-SW 8 Sea: 3-4		Time for rudder hard over: 20ˢ	Name of ship: M/S	STB. HALF AHEAD
		Time to stop engine: ᵐ ˢ	Date of test: 14/9 -86. Time: 14.41	Scale 1:10000 Page 12 of 20

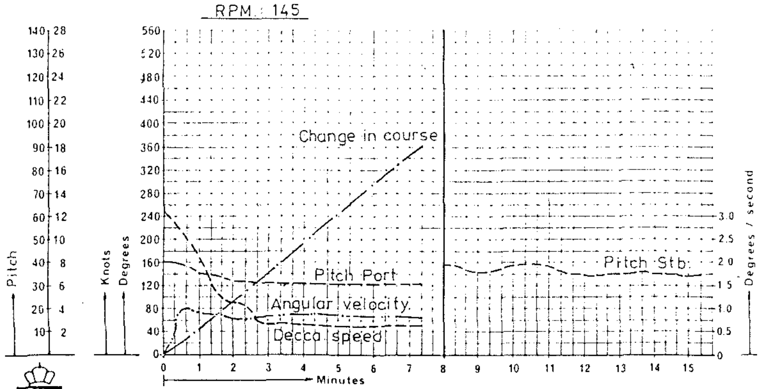
WARNING

ONLY VALID FOR CALM WEATHER. NO CURRENT AND DEEP WATER CONDITIONS WITH CLEAN HULL

0 500 1000 Metres

0 5 Cables





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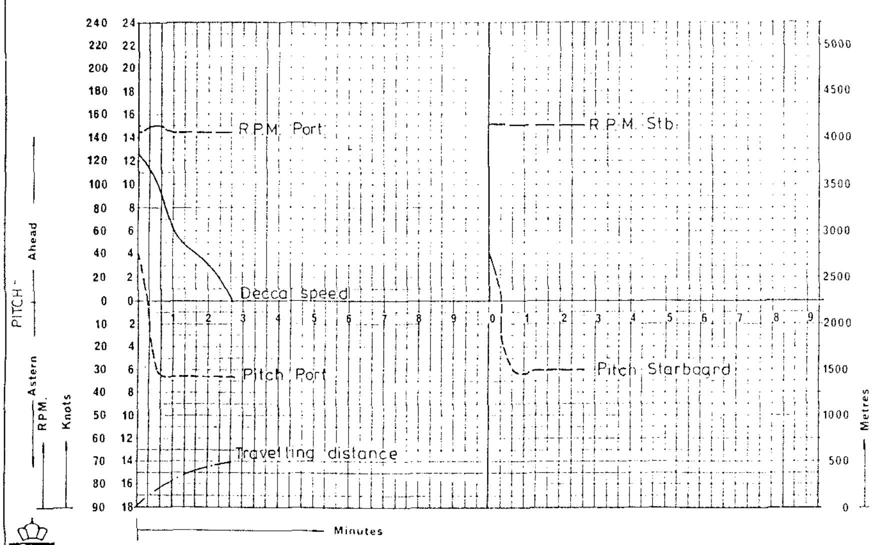
Test area: FÆRDER	Time to rev. propeller: 0ᵐ 18ˢ	Drought fore: 4.45m aft: 4.70m	Nb.no: 204 SMT No: 2 / 84	CRASH STOP
Wind: S-SW-8 Sea: 3-4	Stop time: 2ᵐ 40ˢ	Original course: 159° speed: 12.6	Name of ship: M/S ÖRESUND	HALF AHEAD / FULL ASTERN
Rudder during test: MIDSHIPS	Travelling distance: 490 mtrs.	Change of course during test: 37°	Date of test: 14/9 -86. Time: 15⁰⁵	Scale: 1:10000 Page 15 of 20

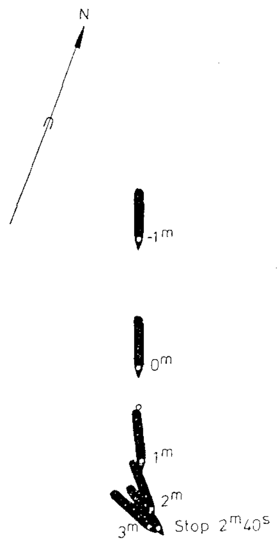
WARNING

ONLY VALID FOR CALM WEATHER, NO CURRENT AND DEEP WATER CONDITIONS WITH CLEAN HULL.

0 500 1000 Metres

0 5 Cables





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