SMSSH '86
15TH JUBILEE SESSION

POWER SAVINGS THROUGH A NOVEL FIN SYSTEM

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ABSTRACT

The following article describes a new flow deflecting fin system developed jointly in the GDR by the Institut für Mechanik of the Academy of Sciences of the GDR, Berlin, and the Schiffbau-Versuchsanstalt, Potsdam, during the past few years. It consists of simple fins of aerofoil cross section positioned forward of the propeller and is equally suitable for both newbuildings and vessels that are already in service. Its main effect stems from a new way of imparting prerotation to the water entering the propeller on the side of the ship on which the propeller blades move upwards. Moreover, part of the energy dissipated in the wake field of the hull can be recovered and used for the propulsion of the ship by selecting appropriate fin arrangements and cross sections.

Experiments with the ship models investigated so far show that power savings of between 2 and 5 % can be achieved. The basic saving of between 2 and 3 % resulting from the prerotation imparted to the water entering the propeller is independent of hull shape.

The report describes the hydrodynamic considerations on which the development of the SVA fin system is based. The results of tests with two models producing very different wake fields are briefly described.

NOMENCLATURE

- C_{Th} - Thrust loading coefficient of propeller $C_{Th} = T/\frac{\varrho}{2} v_A^2 \frac{\pi D^2}{4}$
- D - Diameter of a propeller (m)
- F_D - Towing force in a self propulsion test (N)
- J - Advance number of propeller $J = V_A/n\,D$
- n - Rate of revolution (1/s)
- Δn - Difference of rate of revolution (%)
- P_D - Delivered power at propeller $P_D = 2\pi Q n$ (W)
- ΔP_D - Difference of delivered power at propeller (%)
- P/D - Pitch ratio of propeller
- Q - Torque (Nm)
- ΔQ - Difference of torque (%)
- R_T - Total resistance (N)
- t - Thrust deduction fraction $t = (T - R_T + F_D)/T$
- T - Thrust (N)
- ΔT - Difference of thrust (%)
- V - Speed of ship (kn)
  - Speed of model (m/s)
- V_A - Speed of advance of propeller (m/s)
- V_T - Circumferential component of velocity (m/s)
- W_T - Taylor wake fraktion determined from thrust identity $W_T = (V - V_A)/V$
- Δ - Difference of self propulsion test results with and without fins in general (%)
- η_H - Hull efficiency $\eta_H = (1-t)/(1-W_T)$
- η_R - Relative rotative efficiency
- ϱ - Mass density of water (kg/m^3)

INTRODUCTION

Owing to the great increase in the proportion of the total running costs of a ship accounted for by fuel, the quest throughout the world for ways and means of improving propulsive efficiency, i. e. for better utilizing the energy expended, has intensified in the course of the past two decades.

Besides the "classical" approaches to optimize energy consumption, such as

- improving hull shape to reduce ship resistance and raise propulsive efficiency,
- increasing propeller efficiency and
- improving the efficiency of engines,

during the past few years a variety of devices intended mainly to improve the flow of water to the propeller or to reduce the energy dissipated in the propeller jet have been developed, and in some cases applied in practice, to improve propulsive efficiency.

As reported by R. Wagner in his excellent "Review and Prospects of Counter Propeller Development" in volume 30 of the annual of the Schiffbautechnische Gesellschaft in 1929, the principles by which flow-deflecting arrangements interact with the propeller were known to naval architects and exploited over 70 years ago. Nevertheless, in recent years devices of this kind have been developed, patented and used in various shipbuilding countries, ranging from asymmetric sterns (Nönnecke, Federal Republic of Germany) through nozzles forward of the propeller (Schneekluth, Federal Republic of Germany), guide vanes (Punson, Soviet Union) and reaction fins (Mitsubishi, Japan) to guide vanes on the rudder (Kawasaki, Japan), to mention only a few.

Practicable solutions were also sought in the GDR. The fin system described in this report was developed jointly by the Institut für Mechanik (IMech) of the GDR's Academy of Sciences in Berlin and the Schiffbau-Versuchsanstalt (SVA) in Potsdam and has been thoroughly tested in model experiments. In principle it is suitable for use on all single and multiple screw ships and can also be retrofitted to vessels that are already in service.

BASIC CONSIDERATIONS

The numerous sources of losses in the flow around a ship and in the propulsion arrangements can be divided into two broad categories. The first consists of the losses that arise owing to the principles involved and must be minimized by finding the optimal compromise for each specific design. They include, for instance, the energy of the axial component of the propeller jet and frictional losses on the wall, propeller and rudder. The second category consists of losses that can all theoretically be avoided almost completely, such as flow separation on the after-body, the generation of large, energy consuming eddies and the kinetic energy of the tangential components of the propeller jet, the so called spin losses.

Of the losses in the second category, both flow separation and eddy generation are a result of hull shape and can be reduced or even avoided by the appendage of reaction surfaces. Schneekluth's nozzle forward of the upper part of the propeller disc and Grothues' spoilers to deflect the vertical component of the flow in the boundary layer close to the hull forward of the propeller are well known and typical examples of such devices.

Spin losses can only be eliminated or reduced by "unnatural" means because they are a consequence of energy transfer by rotating parts of a turbine and therefore have no analogy in nature. In performing work, the propeller impresses a tangential component in the direction of its sense of rotation upon the jet.

Since the spin loss is relatively small compared with the other losses, it was not until a few years ago that attention turned to it again in connection with the efforts going on in many countries to reduce energy losses. These efforts resulted in various structures designed to be fixed to the hull, to rotate, or to be supported by the rudder, including asymmetric after-bodies, guide vanes attached to the hull forwards of the propeller to generate prerotation, contra-rotating propellers and Grim's free-wheeling vane wheel, and reaction fins attached to the rudder. The economics of such devices are influenced by the energy savings they bring about, the manufacturing effort involved, reliability, losses caused by the additional components in the water, the transfer of the resultant forces to the hull, and energetic, vibration and other effects.

It can be expected that integrated propulsion concepts using a combination of reaction surface systems to reduce energy losses will be offered as standard in many shipbuilding countries in future. Since the reduction of spin losses involves the least technical effort, an analysis of such losses and of possible ways to reduce them was undertaken as a first step towards an integrated propulsion concept. The design of devices suitable to reduce spin losses is based on a analysis of the energy in the flow around the after-body and at the propeller, the optimal arrangement of the device relative to the propeller, and the appropriate consideration of side-effects.

Fig. 1 represents an energy analysis showing the utilized and lost energy fractions for a free running B 4.55 propeller of the Wageningen series as a function of the advance ratio for a pitch ratio of 1.0. The calculations were performed with a greatly simplified model for free-running propellers. The relative magnitudes of the useful and lost fractions must therefore be regarded only as estimates despite the good degree of agreement between the calculated and measured efficiencies.

Fig. 2 presents another analysis showing the proportion of energy input to the propeller that is accounted for by spin losses for three pitches of the same propeller as a function of the thrust loading coefficient, C_{Th}. It shows that spin losses account for between 4 and 6 % for $C_{Th} = 1$ at a pitch ratio of unity. A small fraction of this is recovered by the interaction of the rudder with the propulsion arrangements even if no reaction surfaces are provided. If such surfaces are appropriately shaped and positioned, the frictional losses they induce can be possible to obtain a reduction in overall resistance. The energy gain, which is at least 2 to 3 % at this propeller pitch and thrust loading coefficient, is a result of the working principles involved. It is stable and reproducible and can be obtained both with models and full size vessels. Owing to the higher Reynold s number of the full size ship, the percentage gain can be expected to be even higher than with the model.

Considered on its own, this achievable energetic gain appears to be relatively modest. It is accompanied by a number of other positive effects, however, the benefits of which can be reaped particulary if the reaction fins or guide vanes are fitted forward of the propeller. Such an arrangement, by modifying the flow to the propeller, permits a more uniform distribution of the work around the propeller disc, thus reducing fluctuations in the forces acting on the blades, thrust eccentricity and vibration. Moreover, this configuration enables the device to be attached directly to the hull, thus facilitating retrofitting to vessels already in service. A further advantage of positioning the fins forward of the propeller is that they can be used additionally to deflect the flow near the wall if the vertical components of the boundary layer are reversed. The recoverable energy in these components can then also be utilized.

To make fullest use of the potential offered by the reaction fins it is also necessary to adapt the propeller to the modified flow pattern. This can lead to an additional 2 % saving in energy by improving propeller efficiency.

DESCRIPTION OF FLOW AT THE STERN AND SELECTION OF FIN SYSTEMS FOR TWO ACTUAL SHIPS

Since the flow of water to the propeller depends on hull shape, it varies greatly from ship to ship. Ships with a fine block coefficient often have an upward-directed flow across the whole radius of the propeller disc at propeller centre level like hull A in Fig. 3., whereas the vertical components of the flow often reverse their direction near the wall of ships with a fuller block coefficient, such as hull B, owing to large eddies in the wake field on either side of the ship. These energy-dissipating eddies are caused by the shape of the frames of the fore and middle-body, and they can usually only be slightly influenced by structural arrangements farther aft, including asymmetric stern designs. The provision of reaction fins on the hull to generate prerotation in the water forward of the propeller is also an appropriate way to avoid at least part of the energy dissipation in such secondary eddies caused by hull B.

The fin system developed by SVA consists of simple components of aerofoil cross section attached to the hull forward of the propeller. The actual configuration depends on the flow pattern caused by the hull in the water entering the propeller disc, consisting in general of a horizontal and, if necessary, a vertical fin fitted to either side of the hull level with the propeller shaft. In the simplest case, such as hull A, the fin system consists of only a single horizontal fin on the side of the vessel on which the propeller blades move upwards. The purpose of this arrangement is to deflect the upward, or energetically "incorrectly rotating" flow downwards. On the other side, the flow already takes the energetically desirable direction of its own accord.

For hull B the fin system consists of a horizontal fin on the "upward" propeller side, which deflects the flow downwards over the whole radius of the propeller, and a much shorter fin on the other side to deflect the "incorrectly rotating" component of the flow in the boundary layer close to the wall.

It is naturally best to use as few fins as possible since the optimization of the system and the construction of the full scale structural components becomes increasingly complex as the number of fins increases.

MODEL EXPERIMENTS

The effects of the new fin system were tested mainly by selfpropulsion experiments. The main criterion used for optimization was minimization of the power needed for propulsion, attention simultaneously being paid to possible side effects affecting vibration characteristics. Since the aim of the self-propulsion experiments was to detect differences in the region of one per cent, particular care was called for. For every test series, for instance, the tests with and without fins were performed on the same day to eliminate right from the start all experiment errors that might be caused by differences in test conditions.

The results of the self-propulsion tests with optimal fin configurations for hulls A and B are presented in Fig. 4 and 5. The benefits are expressed as percentage reduction in thrust, torque and propeller speed, and in the propulsion power calculated from torque and propeller speed, obtained through the effects of the fin system relative to the same hull without fins.

As can be seen from Fig. 4, the power saving was over 2,5 % for hull A and varies almost in proportion to the speed. It stems mainly from a reduction of at least 2 % in propeller speed. The fact that the thrust remains unchanged permits us to conclude that the fins produce a thrust that is at least equal to the additional resistance they cause.

Fig. 5 shows that for hull B the reduction in propulsion power required is between 4 and 5 % and is almost constant for the speed range investigated. This power saving results from a reduction of almost 3 % in the necessary propeller speed, largely due to the generation of prerotation forward of the propeller disc, and of roughly 2 % in the torque requirement and even in thrust. It may be concluded from these results that the saving in power requirement cannot be attributed alone to the utilization of the better propeller inflow conditions caused by prerotation induced in the water flowing to the propeller by the fins, but that, in the case of hull B, less energy was dissipated in the whole of the flow to the propeller owing to at least partial suppression of eddy generation as described in chapter 3.

The thrust deduction fractions, wake fractions and ralativ rotativ efficiencies, with which the naval architect is more conversant, are shown without correction as calculated from the propulsion tests in Fig. 6 and 7. The thrust deduction fractions were calculated for the models with and without fins using the resistance without fins or other appendages. The wake fractions were ascertained in the customary way for identical thrusts.

It is evident from Fig. 6 that the thrust deduction fraction, t, remains approximately the same for hull A because the thrust does not change, whereas the wake coefficient, W_T, increases as a result of the reduction in propeller speed permitted by the fin system. The hull efficiency, $\eta_H = (1-t)/(1-W_T)$ is therefore correspondingly higher. The close agreement between the values of η_R for the hull with and without fins is a consequence of the care mentioned earlier with which the experiments were performed.

Fig. 7 shows that for hull B the influence of the fin system on the parameters characterizing the relative hull efficiency are greater owing to the greater effect of the fins. The thrust deduction fraction, t, is smaller as a result of the lower thrust required, and the wake coefficient, W_T, is larger due to the lower propeller speed. The values of η_H for the model with fins are considerably higher than for that without them, but, as in the case of hull A, the values of η_R are almost identical for both versions.

CONCLUSIONS

It has been shown that the new SVA flow deflecting fin system we have described, and which has been the subject of numerous tank tests, can yield power savings of between 2 and 5 % for several single-screw ships with low thrust-load coefficients, and that these savings will be even larger on the actual ships concerned owing to the higher Reynold's numbers. The basic gain of 2 to 3 % resulting from the generation of prerotation in the water flow to the propeller can theoretically be obtained with the new fin system for all ships if the propeller load is high enough. This basic gain represents a saving that is independent of hull shape.

The fin system is not only suitable for newbuildings, but can also be retrofitted to vessels already in service. In the latter case, however, it is necessary to check whether the propeller and propulsion arrangements permit the corresponding reduction of 2 to 3 % in propeller speed. Where newbuildings are concerned, of course, the propeller must naturally be adapted to the propulsive arrangement with reaction fins. This will yield an additional saving in power.

Apart from its principal effect, the reduction of power requirements, the fin system, owing to the asymmetric fin arrangement, also results in more uniform loading of the propeller disc, thus probably reducing vibration induced by pressure pulses, thrust eccentricity, and susceptibility to cavitation.

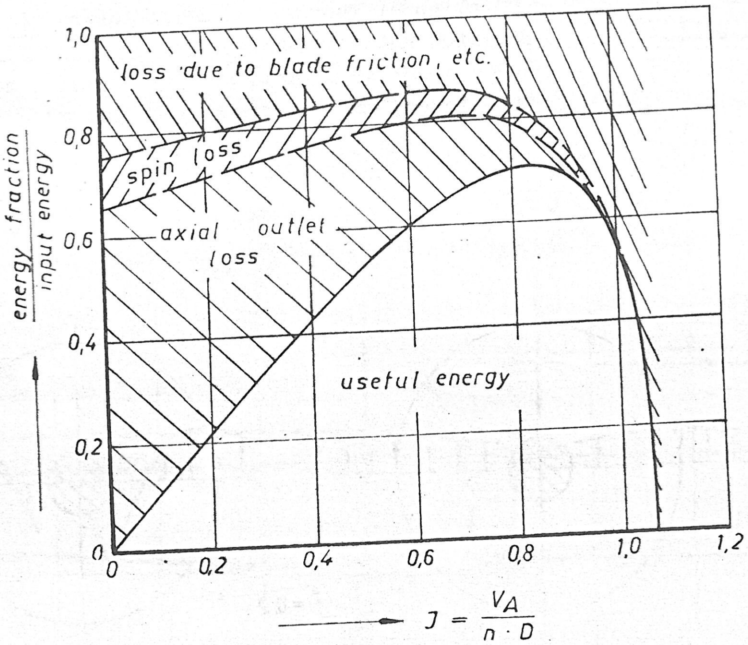

Fig. 1. Energy Balance for a Wageningen B 4.55 Propeller with a Pitch Ratio of 1.0 in Open Water

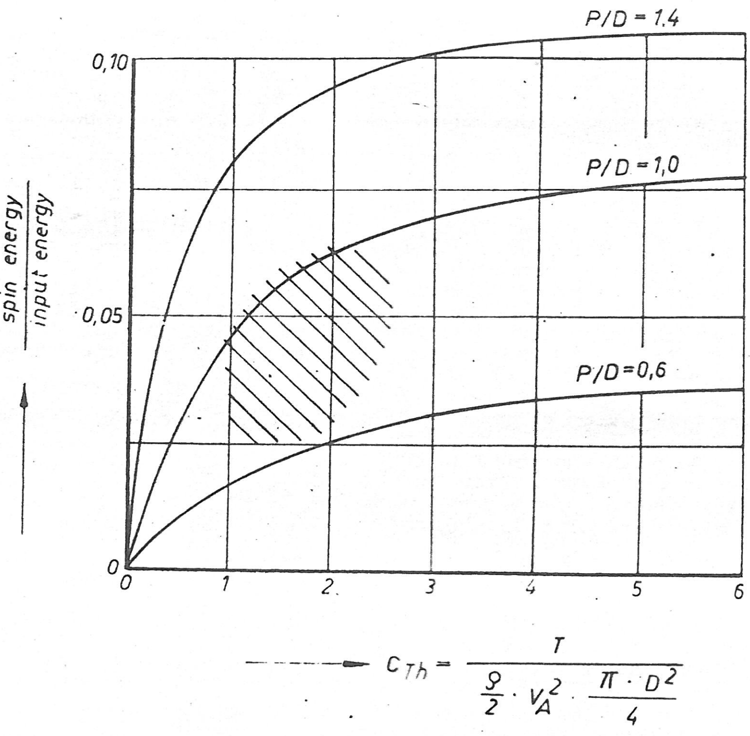

Fig. 2. Spin Loss of Wageningen B 4.55 Propeller as a Function of Thrust Load Coefficient, C_{Th}, and Pitch Ratio, P/D
Shaded Area: Working Range for Normal Single-Screw Vessel

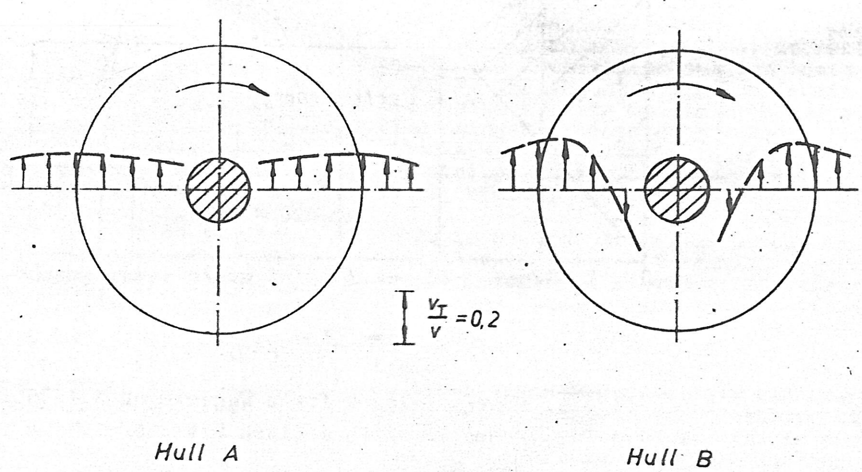

Fig. 3. Tangential Velocity Components in the Propeller Disc Plane

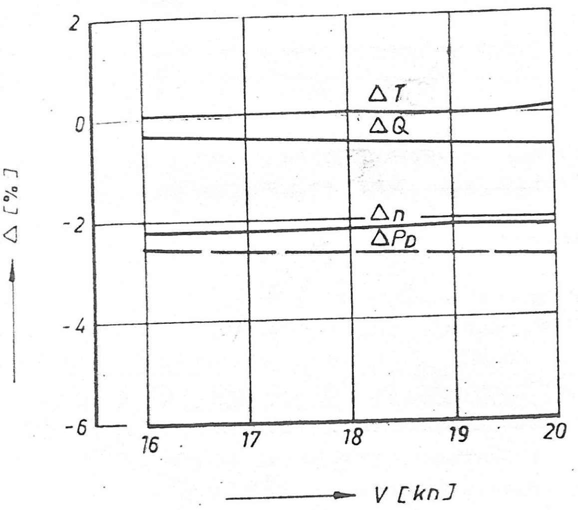

Fig. 4. Hull A, Influence of Fins on Measured Propulsion Values

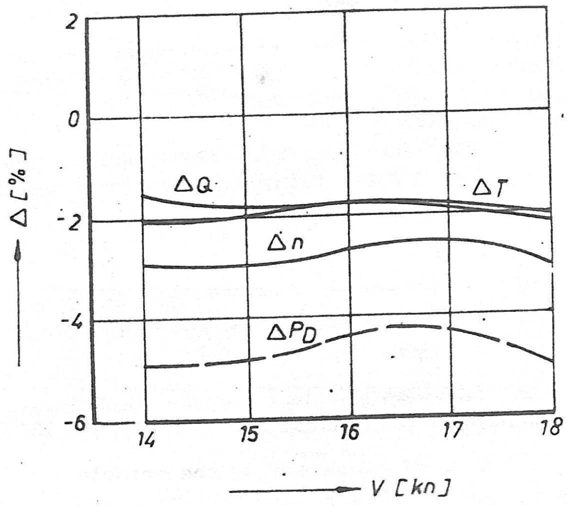

Fig. 5. Hull B, Influence of Fins on Measured Propulsion Values

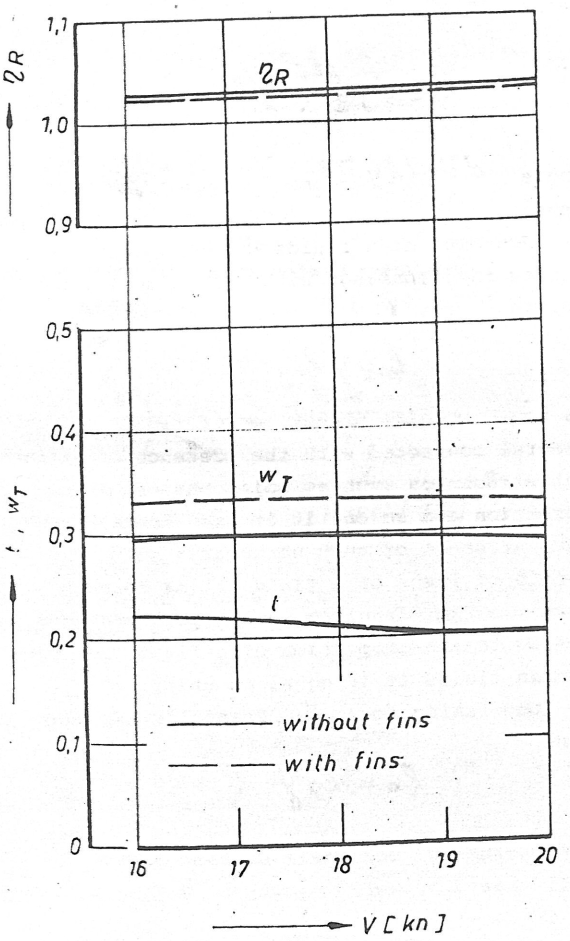

Fig. 6. Hull A, Propulsion Parameters

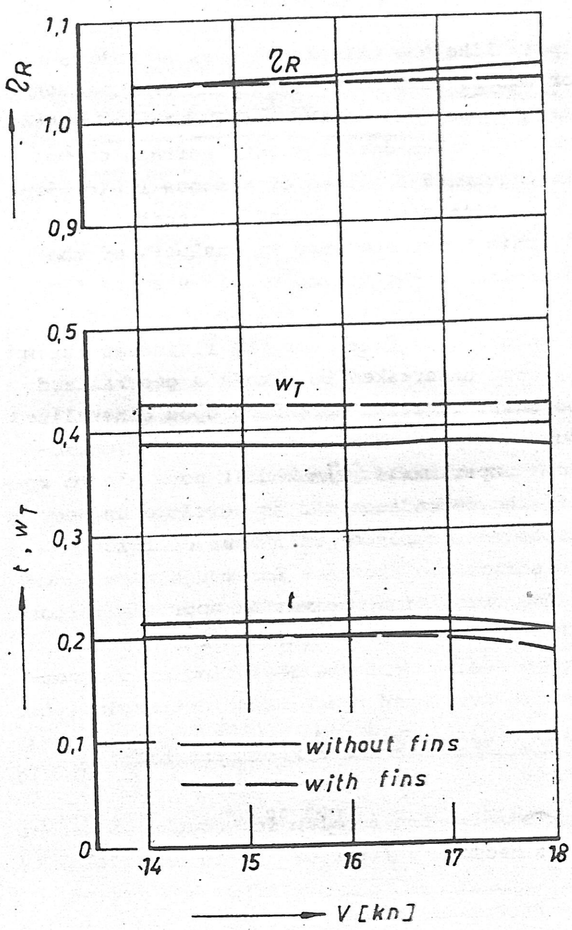

Fig. 7. Hull B, Propulsion Parameters