Unconventional geometry improves propeller efficiency

Work by Danish and German naval architects has resulted in a novel design, the Kappel propeller, which features winglets

PROPELLERS with improved efficiency due to unconventional geometry have been developed by a team of Danish and German naval architects. The work by Professor P Andersen, S V Andersen, PhD, Professor H Schwanecke and J J Kappel, which has lasted more than a decade, was inspired by NASA work on non planar aircraft wings where efficiency gains were obtained with wings being bent upwards – or downward – towards the tips. When this team attempted to apply NASA's development to propellers, initial experimental work in 1980/82 clearly showed that existing calculation methods could not be used. Deviation from propellers based on straight helices required the development of theoretical and mathematical instruments much more complicated than used for conventional propellers or for the NASA development, where a winglet could more or less be fitted to an existing wing.

The majority of screw propellers in service today are developed by means of theories based on a simple helical surface generated by a straight line, which has been the basis for screw propellers for ships and airplanes for more than a century; the validity of propeller theories have as a consequence generally been limited to this geometry. The optimum theoretical blade load distribution for such propellers was developed by Betz in the 1920s, and to a certain extent this load distribution is comparable to the ideal elliptical load distribution of a straight aircraft wing also developed in this period.

In the past however, alternative solutions to the straight wing and the straight screw propeller have been sought. In this context aircraft wings with sweepback and propellers with skewback are considered conventional wings and propellers. In 1924 Prandtl and Betz conducted a series of wind tunnel tests with wings with end plates. A positive gain was found, especially for short wings, but in general the efficiency advantage was lost at loads corresponding to cruising conditions.

Some 50 years later in the mid 1970s, NASA took up the idea of wing tip modification. Whitcomb and others by extensive calculation and model testing developed aerodynamically shaped fins called winglets that were fitted at the wing tips instead of end plates. End plates or winglets fitted to airplane wings or to propeller blades can improve efficiency when fitted to the wing/blade suction side, but less so when fitted to the pressure side.

The reason for this difference in effect is that an element fitted to the pressure side will reduce the induced drag and the induced lift, whereas an element fitted to the suction side will reduce the induced losses by an equal amount and at the same time induce additional lift. By careful optimisation Whitcomb and his colleagues were successful in developing a wing and winglet that were efficient for wings of modern airplanes at cruising conditions. Such wings with winglets can be seen on the Boeing 747-400 and the Airbus A430 passenger jets, and other modern airplanes.

After the mathematical tools and initial computer programs for propellers of arbitrary shape deviating from the straight helices had been created at the Technical University of Denmark, a small series of propellers with medium load was tested by Professor Schwanecke in the model tank in Berlin. Model tests which have been published showed efficiency gains of 3% and power savings of 5% in the actual working condition behind the ship.

A propeller model for a large single-screw 25-knot container ship has been tested in the model tank in Hamburg. This time an efficiency gain of 4% was obtained and a power saving in the actual behind condition of 2.8% was obtained compared with competing propellers. Considering that propellers for fast single-screw container ships are some of the largest and most difficult propellers to design and that the efficiency is already very high even for conventional propellers – wherefore less improvement is to be expected – the results were very encouraging even though this

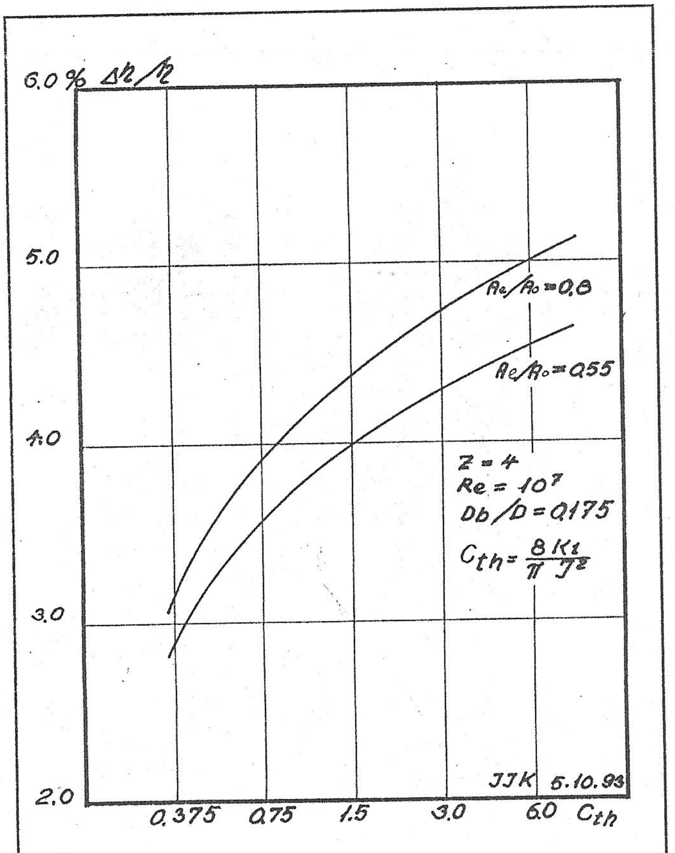
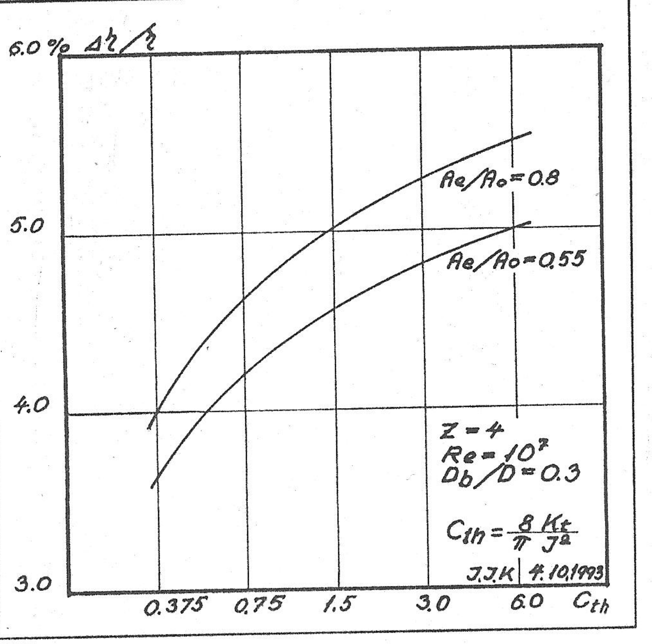


Fig 1 (left). Open water efficiency gain for optimised four-bladed Kappel propellers compared with efficiency of optimised conventional propellers with a boss diameter ratio of 0.175. The efficiency gains are consistent with model tests.

Fig 2 (below). Open water efficiency gain for optimised four-bladed Kappel propellers compared with efficiency of optimised conventional propellers with a boss diameter ratio of 0.3. The efficiency gains are consistent with model tests.



propeller was not chosen in the end.

The system developed is capable of designing almost any propeller geometry. The blade could be bent towards the pressure side or towards the suction side, and the bend could be more or less sharp. However, based on numerous calculations, parametric studies and model tests we have found that propellers with blades bent smoothly towards the suction side represent a very good compromise with respect to efficiency, cavitation behaviour and manufacture. The expected gains in efficiency based on parametric studies and consistent with model tests are shown in Fig 1 for a boss diameter ratio of 0.175 and Fig 2 for a boss diameter ratio of 0.3. A wire mesh drawing of a five-bladed propeller, developed in co-operation with Stone Manganese Marine and suitable for a fast single screw container ship, is shown in Fig 3.

The team has continued to improve its design methods and mathematical tools. In particular, it has been possible, by means of mathematical methods and parametric studies, to optimise further the propeller design with respect to load distribution and propeller geometry including skew. This potential for improvement is expected to be verified in further tests.

A licence agreement for the development, manufacture and marketing of this design, which is called the Kappel propeller, has been concluded for fp propellers between Stone Manganese Marine and J J Kappel Marine Concept. A number of interesting inquiries have been received from European and American shipowners, shipyards and propeller makers, and negotiations with major European shipyards for the application of the Kappel Propeller are ongoing. ⓣ

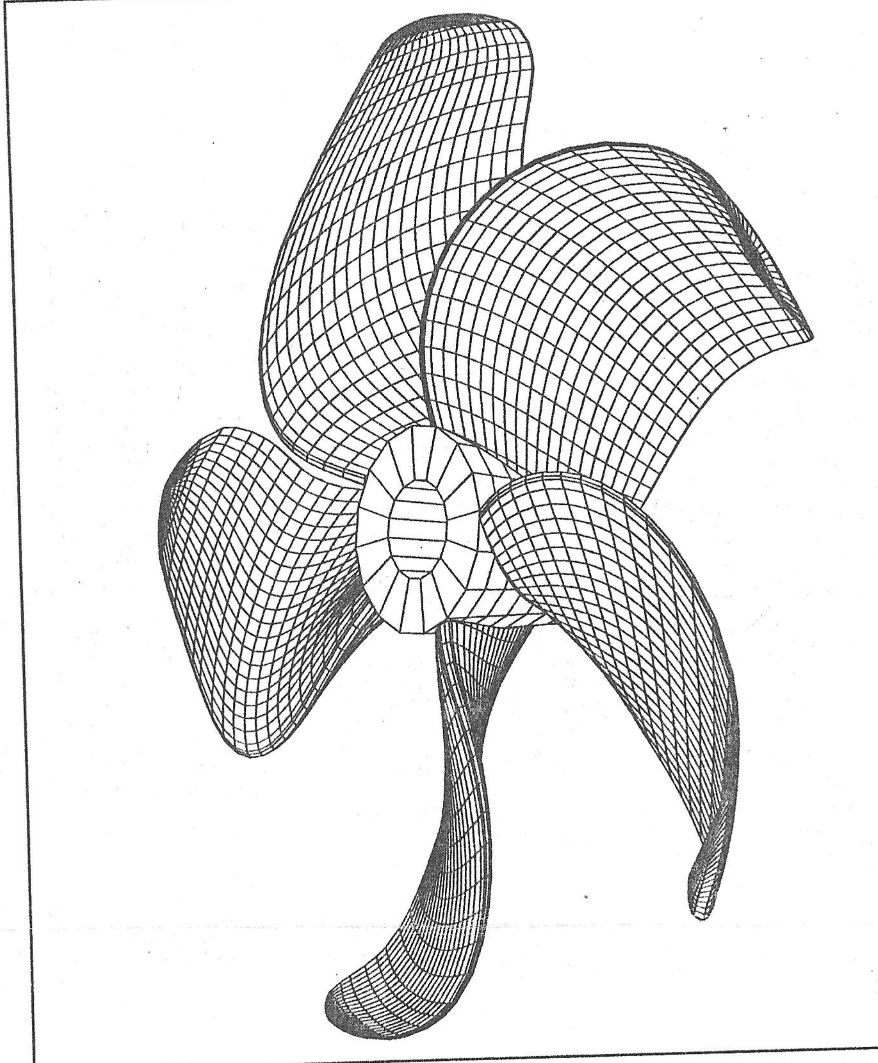


Fig 3. A wire mesh drawing, generated by Stone Manganese Marine, of a five-bladed Kappel propeller suitable for a fast single-screw container ship.