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P.O.Box 58, 9003 Varna, Bulgaria, Tel.: +359 52 773 793, Fax: +359 52 600294, E-mail: hadmar@bshc.bg

# The Efficiency of Pod Propulsion

**Friedrich Mewis**
**Hamburgische Schiffbau-Versuchsanstalt GmbH**
**Hamburg, Germany**

## 1 Introduction

Within the past 10 years, Pod Drives (propulsors with outboard electric motor) with a power of up to 21 MW per unit have been developed and put into service; especially for large cruise liners but also for Ro-Ro-ferries and supply vessels. The success of Pod Drives is due to several advantages that they have over the conventional, shaft drive arrangement. These advantages include better maneuverability and lower noise generation. Also, there is a potential for more payload because the constraints on the machinery layout are less severe: There is more freedom in choosing the location of the main engines.

The question of the hydrodynamic efficiency of pod drives has played an important role in many discussions. HSVA has carried out investigations into this question and has came to a clear conclusion: The hydrodynamic unit efficiency is lower than that of the conventional propeller with a rudder as a unit. However, the propulsion efficiency is only one (small) aspect of the advantages and disadvantages of pod drives.

It is very important that the open water tests for the pod unit be carried out in a standardized manner to allow a comparison of the hydrodynamic pod efficiency. The open water unit test procedure of HSVA is described in Section 4. A few results of open water unit tests are presented additionally in order to show the influence of the test conditions on the test results. Especially the influence of the propeller gap on the measured results is discussed..

## 2 Pros and Cons of Pod Propulsion


The Azipod unit incorporates an electric AC motor, located inside the pod.

**Fig. 1 Definition Pod Drive/Azipod [1]**

Pod drives are characterized by two main qualities:

- Electric motor is located inside a Pod
- The total unit is azimuthing

One of the largest pod installations up till now, the cruise liner “Millennium” built by “Chantiers de L’Atlantique”, is shown in Figs. 2 and 3 in full scale and in model scale (1:25). These pod units are manufactured by Rolls Royce-KAMEWA/Cegeleg.

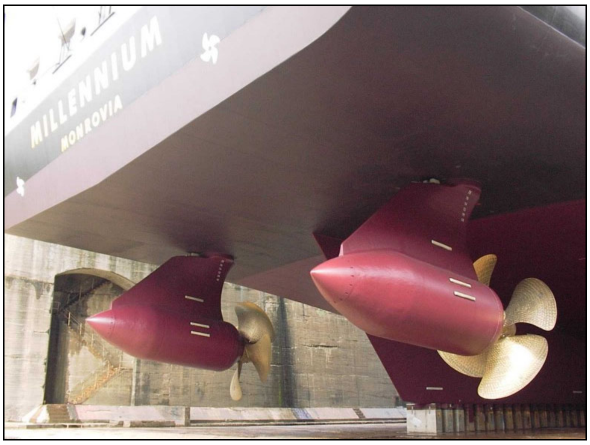

**Fig. 2 Two KAMEWA-Pods with 21 MW each on the Cruise Liner “Millennium”**

**Fig. 3 Two KAMEWA-Pod-models on the model of the Cruise Liner “Millennium”**

The advantages and disadvantages of Pod-Drives in general are discussed thoroughly by the author in [2]. The main results of this analysis are summarized here:

The advantages of the pod drives are (in order of their significance):
- More cargo space because the engine can be located more freely.
- Better manoeuvrability.
- Lower noise level.
- Low speeds are possible.
- Suited as booster drive in order to increase the speed.
- Less working expense in ship manufacturing
- Power requirement can be lower for twin screw ships.

The disadvantages of the pod drives are (in order of their possible significance):
- Higher capital costs
- Diesel electric system required (power loss).
- Power requirement higher for single screw arrangements.
- Limitation in power.
- Limitation in speed.

| | Limitations up till now | And in the future |
|---|---|---|
| Maximum power per unit | 21 MW | 32 MW |
| Maximum possible speed | 26 kts | 30 kts |
| Max. realized propeller diameter | 6 m | 8 m |

**Table 1 Limitations up till now**

These limitations reduce the applicability of pod propulsion for fast ships and for ships with a very high power requirement.

It is not easy to realistically judge the suitability of pod propulsion for different ship types based on these advantages, disadvantages and limitations. A deeper analysis leads to the following order of suitability for some ship types [2]:

Very well suited for:
Cruise Liner, twin screw
RoRo-Passenger Ferry, twin screw, V < 26 kts (V < 30 kts in preparation)
Icebreaker

Well suited for:
Supply Vessel
Bulker/Tanker, twin screw
Bulker/Tanker, single screw

Hardly suited for:
Container Vessel, single screw, < 1000 TEU
Container Vessel, single screw, 1000 to 3000 TEU

Not well suited for:
Container Vessel, twin screw, 1000 to 3000 TEU
Container Vessel, twin screw, 3000 to 6000 TEU

Not possible for:
Container Vessel, single screw, > 3000 TEU

## 3 Propulsion Efficiency

As mentioned in Section 2 the propulsion efficiency of the pod drives does not play a very important role in the decision to select a pod drive as main propulsor.

When compared with the efficiency of a propeller alone, the propulsion efficiency of a single pod unit is lower. A realistic conclusion can only be drawn if the unit efficiency of the propeller with pod is compared with the unit efficiency of the conventional propeller with rudder arrangement. HSVA has carried out a test series for different pods and conventional propeller-rudder installations. Figures 4 and 5 show a comparison of the unit efficiencies of a propeller- pod unit and a propeller-rudder unit.

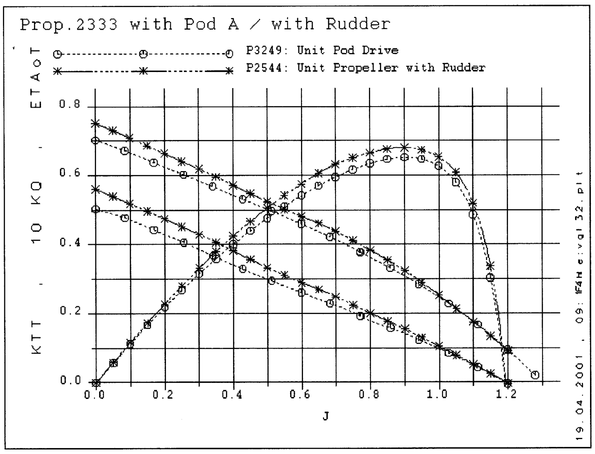

Fig. 4 Comparison of open water characteristics, pod drive – propeller with rudder

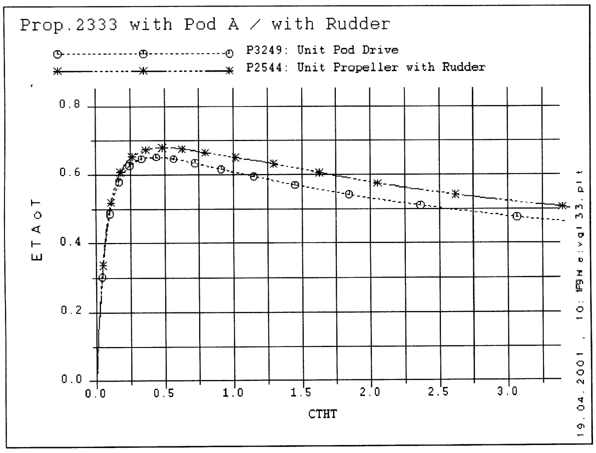

Fig. 5 Comparison of open water efficiency, pod drive – propeller with rudder

This comparison is based on the measured unit thrust of the pod and the propeller-rudder unit together with the propeller torque. If the propeller thrust is used for a comparison instead of the unit thrust, the results become misleading. The propeller thrust does not include the resistance of the pod housing/rudder, and the measurement of the propeller thrust is influenced significantly by the test conditions for pod units, see Section 5. of this paper.

Figures 4 and 5 demonstrate that the subject pod unit has about a 5% lower efficiency than a unit consisting of the identical propeller with rudder. All values are uncorrected values in model scale.

In many cases an additional small loss in efficiency for pod units is present because the pod propeller cannot have optimal diameter due to the torque limitation of the pod motor.

A small gain in propeller efficiency can be expected for twin pod arrangements because the inflow to the propeller is more uniform (absence of shafts and shaft brackets). This leads to better design conditions for the propeller and therefore to higher propeller efficiencies.

In general, pod driven single screw ships would have a lower propulsion efficiency than conventional single screw ships. By optimizing the ship form for pod conditions this loss can be reduced. Pod driven twin screw ships generally have a lower propulsion efficiency also, but the power demand can nonetheless be higher for conventional propulsion because the resistance of the appendages is higher than the resistance of the pod housings in most cases. An additional advantage for pods in twin screw applications comes from the greater freedom for the arrangement of the pods in the optimal position and with optimal alignment.

## 4 Description of the Procedure for Open Water Unit Tests of Pod Units

The Open Water Unit Test is an open water test for the complete pod unit consisting of propeller and pod housing. A special device is required for carrying out this test. At HSVA this device is called the "Propeller Boat".

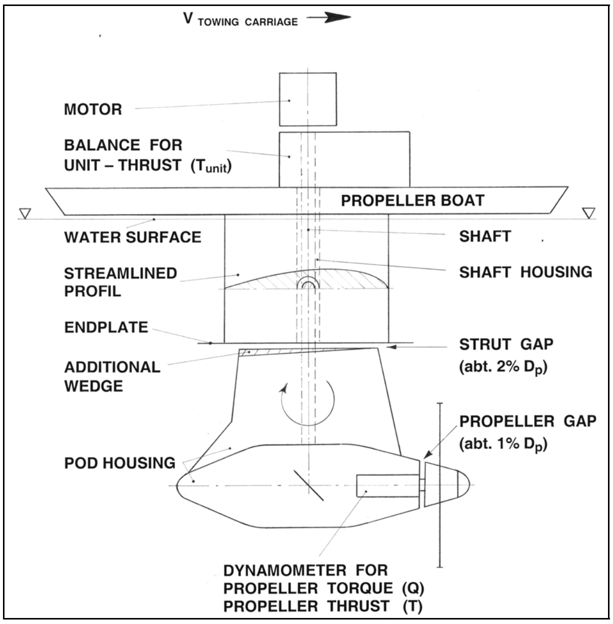

**Fig. 6** **Pod –drive in open water unit test**

It is recommended to carry out the Open Water Unit Test in the following manner (see Fig. 6):
The propeller is driven by a motor at the top via a belt or gear drive in the same manner as in the propulsion test. In order to avoid an influence of the water surface, the propeller shaft must be submerged at least 1.5 x $D_P$, or preferably better 2 x $D_P$. The free part of the shaft between the upper end of the pod and the bottom of the propeller boat must be protected by a streamlined profile in order to avoid drag on the shaft itself. This profile which may not much the pod strut profile is fixed to the bottom of the propeller boat. The bottom of the profile is fitted with a thin endplate in order to minimize the effects in the strut gap. The endplate is arranged parallel to the water surface.

The bottom of the propeller boat has to be 5 to 10 mm above the water surface in order to avoid waves caused by the strut piercing the surface.

The propeller shaft must be arranged parallel to the water surface. In most cases this arrangement leads to an open wedge at the upper, aft end of the pod strut. This open part should be filled out with an additional wedge in order to make the upper surface of the pod strut parallel to the endplate of the streamlined profile and to ensure an uniform strut gap.

The width of the propeller gap has an unavoidable, large influence on the measured propeller thrust. For that reason it is very important to have fixed rules for the gap width. The recommendation is that the width of the propeller gap is to be about 1% of the propeller diameter. The width of propeller gap has no influence on the unit thrust.

The width of the strut gap has a small influence on the measured thrust of the unit. This gap must be parallel to the water surface. The recommended width of the strut gap is about 2% of the propeller diameter.

The thrust and torque of the propeller, $T$ and $Q$, should be measured using a dynamometer on the propeller shaft positioned as close as possible to the propeller in order to avoid effects from mechanical friction. Alternatively the torque can be measured at the top of the unit, but in this case mechanical losses must be accounted for by replacing the propeller by a dummy hub of the same mass. The thrust of the whole unit, $T_{unit}$, is to be measured using a balance at the junction between the strut and the propeller boat. The propeller boat is fixed to the towing carriage. The rotation rate of the propeller, $n$, and the velocity of the towing carriage are to be measured in the usual manner.

## 5 Special Experience with Pod Open Water Unit Tests

### 5.1 Reynolds Number Effects

Two parts of the Reynolds number effects must be taken into consideration. The first part is the Reynolds number effect between the open water unit test and the propulsion test. The second part is the correction from model scale to full scale.

At first some remarks to the Reynolds number effects in model scale shall be made. If the pod models are large enough to reach propeller Reynolds numbers higher than $5 \times 10^5$ the Reynolds effects for the pod housing are in general small. In this case the pod model is working in a stable region with full turbulent flow.

Fig 7 shows the effect of propeller speed on the pod efficiency on the basis of the measured propeller thrust. The propeller gap is 3 mm and strut gap is 5 mm. For J = 0.9 the variation from $n = 12$ *rps* to $n = 18$ *rps* corresponds to Reynolds numbers of $Rn = 4 \times 10^5$ to $Rn = 6 \times 10^5$.

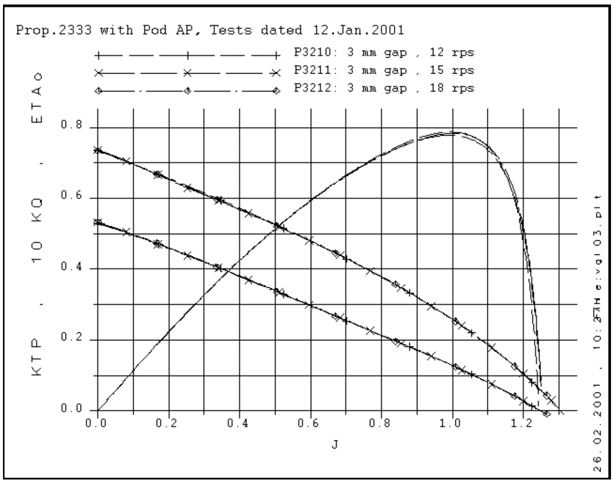

**Fig. 7** Open water characteristics of a pod unit **based on measured propeller thrust** for different propeller speeds

Fig. 8 shows the same relations for the case that the measured unit thrust is used instead of the propeller thrust for the open water characteristic.

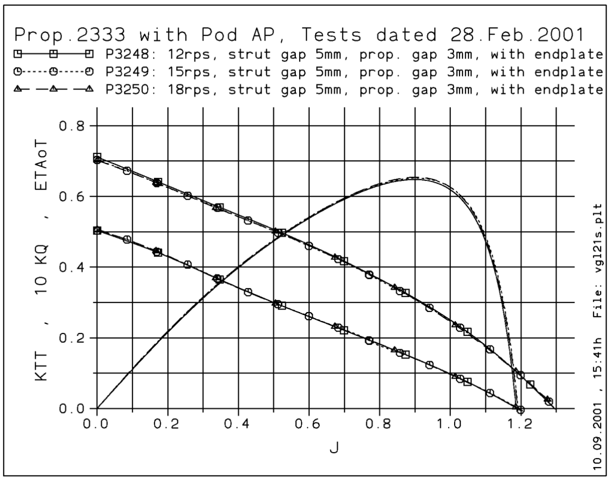

**Fig. 8** Open water characteristics of a pod unit **based on measured unit thrust** for different propeller speeds

In both cases the Reynolds number effect in model scale is negligible within the investigated range. A comparison of the efficiency based on propeller thrust in Fig. 7 and based on unit thrust in Fig. 8 shows a very significant difference. The efficiency based on propeller thrust is considerably higher than that based on unit thrust.. The efficiency based on measured propeller thrust should not be used for comparison purposes, see Section 5.2 of this paper.

The correction to full scale of the $K_T$ and $K_Q$ values of the pod propeller should be carried out in the same manner as for the propeller alone, for example according to ITTC 1978. HSVA uses it's own method which was development by Meyne [3] on basis of Lerbs' theory. The drag of the model pod housing should be corrected according to the particular experience of the model basin.

## 5.2 Gap Influence on Measured Thrust

For a pod with pulling propeller, the width of the gap between the propeller and the pod housing has a significant influence on the propeller thrust measured. The measured propeller torque is also influenced, but to a lesser degree. Fig. 9 shows these effects.

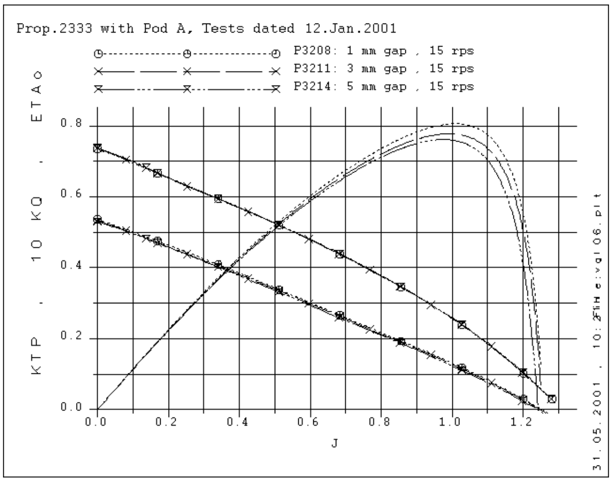

**Fig. 9** Open water characteristics of a pod unit **based on measured propeller thrust** for different propeller gap widths

The reason for this influence is the pressure field in the gap which is located behind the propeller, see Section 5.3.

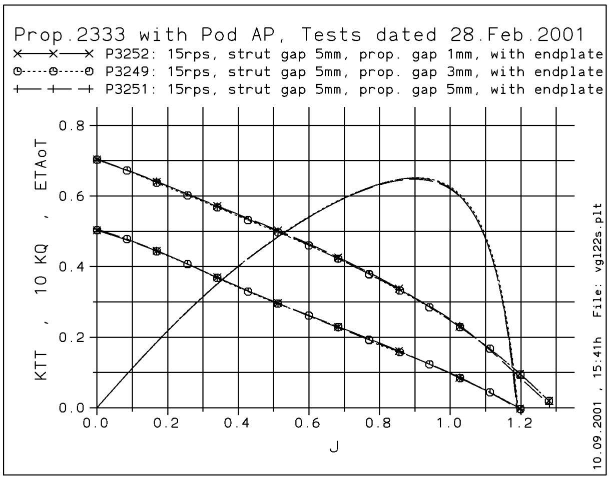

**Fig. 10** Open water characteristics of a pod unit **based on measured thrust of the unit** for different propeller gap widths

Fig. 10 shows that the measured unit thrust is not influenced by the width of the propeller gap. The width of the gap between the upper end of the strut of the pod housing and the profile which is protecting the shaft (Fig. 6) has an influence on the measured unit thrust. The influence is much smaller than the influence of the propeller gap on the propeller thrust, see Fig. 11.

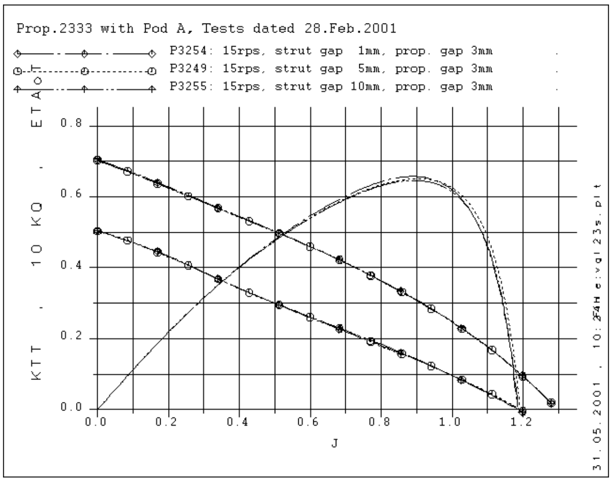

**Fig. 11** Open water characteristics of a pod unit **based on measured thrust of the unit** for different strut gap widths

## 5.3 Measurement of the Pressure in the Propeller Gap

A schematic representation of the propeller open water test setup for conventional propellers and for pod units is shown in Fig. 12.

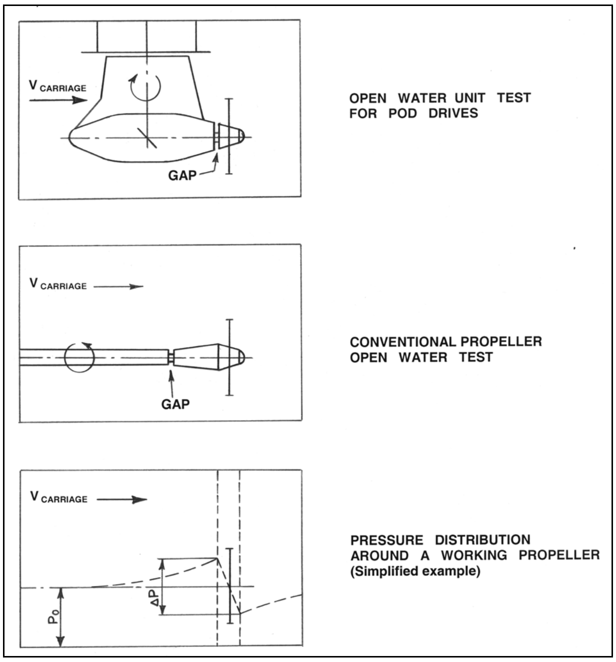

**Fig. 12** Open water test setup

In the diagram it can be seen that the influence of the propeller gap on the pod propeller thrust is nearly unavoidable because the propeller gap is located in a high pressure region behind the working propeller. The design of the propeller open water equipment from Kempf & Remmers used at HSVA for conventional propellers avoids this influence as the gap is further back from the propeller.

Because the propeller gap has a big influence on the measured propeller thrust and torque HSVA has carried out measurements of the pressure in the propeller gap of a pod housing for different conditions.

Eight pressure taps were arranged at equal angular positions around the gap. Fig. 13 shows the measured pressures for one forward speed and for three different propeller gap widths as a function of angular position with the propeller working.

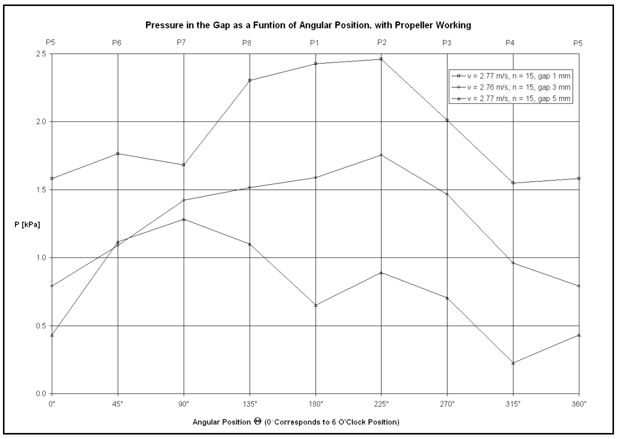

**Fig. 13** **Pressure in the propeller gap as a function of the angular position, propeller working**

In all of the following figures the average pressure in the gap is used.

Fig. 14 shows the pressure in the propeller gap for three different gap widths and three different propeller speeds, all at the same advance speed.

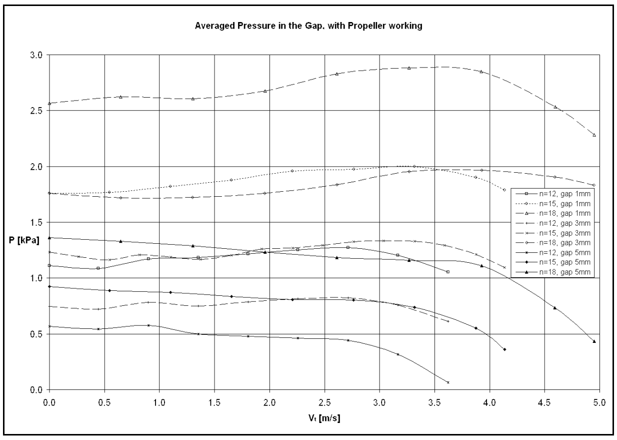

**Fig. 14** **Pressure in the propeller gap for different conditions of the speed, propeller working**

Fig. 15 shows the same results as in Fig. 14, but in this case the pressures have been made non-dimensional as follows:

$$C_P = P/0.5 \cdot \rho\, (\pi \cdot n\, d_H)^2 \qquad (1)$$

with $P$ = pressure [Pa]
$n$ = number of revolutions [1/s]
$d_H$ = hub diameter [m]

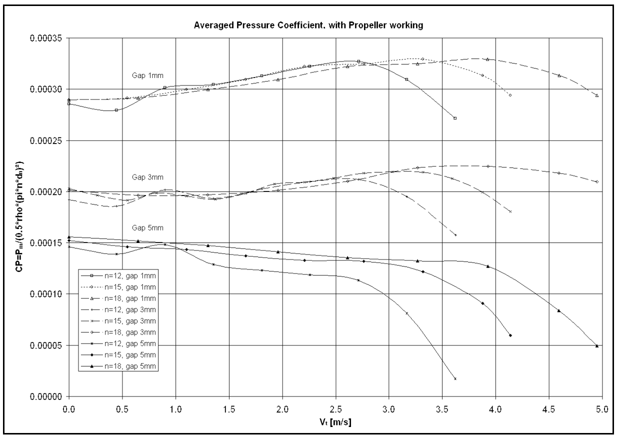

**Fig. 15** **Pressure coefficient $C_P$ in the propeller gap for different conditions, propeller working**

The coefficient $C_P$ is nearly constant for each gap width.
In order to isolate the influences of the working propeller and its rotation on the pressures in the propeller gap, additional tests were carried out with a dummy hub both rotating and not rotating. Fig. 16 shows an example of the results with a propeller gap of 3 mm and number of revolutions $n = 15$ *rps*.

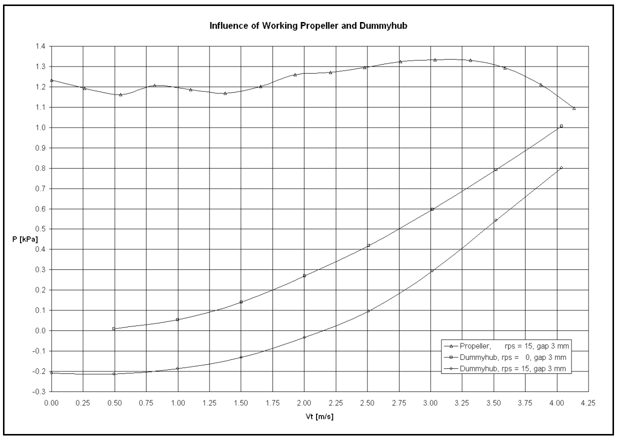

**Fig. 16** **Pressure in the propeller gap with working propeller, dummy-hub turning and not turning**

On the basis of these results and on those of further measurements, a correction of the measured propeller thrust for varying gap width seems to be possible [4].

## 6 Acknowledgement

Most of the above results of measurements were accumulated within an HSVA research project “Reynoldszahleffekte an Pod-Antrieben”, which was partially funded by the German Government, Bundesministerium für Bildung und Forschung.

The author would also like to thank Mr. Roland Kleiter and Mr. Alexander Mrugowski, both students at the Fachhochschule Kiel, for their diligent work on this project during their technical internship at HSVA.

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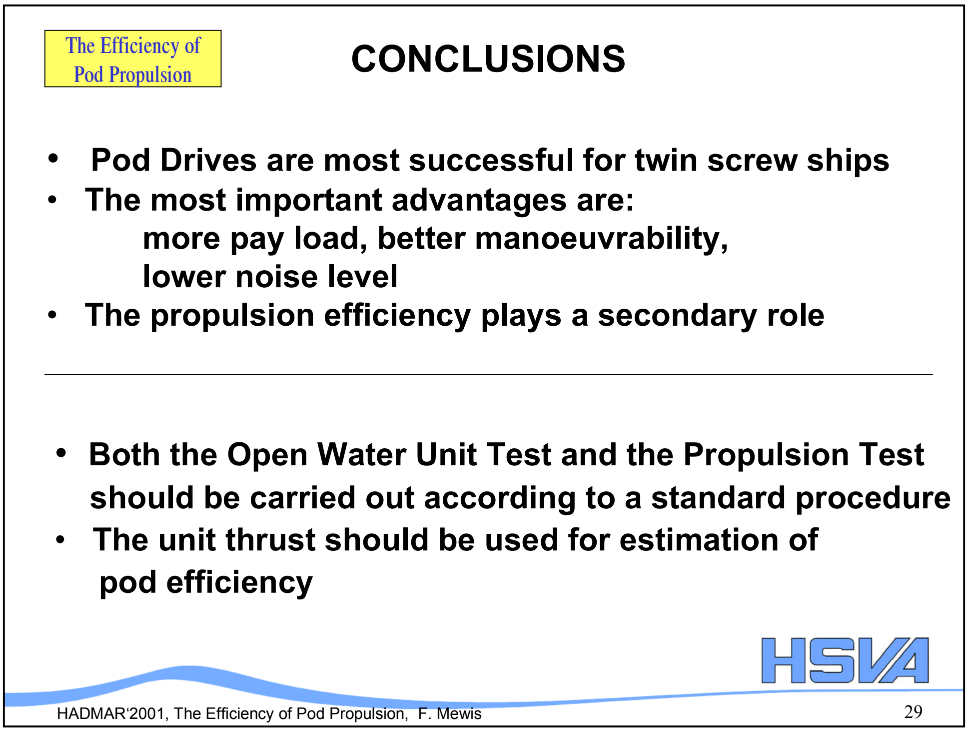

The Efficiency of Pod Propulsion

**CONCLUSIONS**

- **Pod Drives are most successful for twin screw ships**
- **The most important advantages are:**
  **more pay load, better manoeuvrability,**
  **lower noise level**
- **The propulsion efficiency plays a secondary role**

- **Both the Open Water Unit Test and the Propulsion Test should be carried out according to a standard procedure**
- **The unit thrust should be used for estimation of pod efficiency**

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