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Multi-Purpose Ducted CP-Propellers, Some Design and Operation Problems

No. 13

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ABSTRACT

The aim of this paper is to give some idea of the difficulties which can arise at the design and operation of multi-purpose ducted CP-propellers.

The most important problems are the contradictory requirements of bollard pull and push forces, but simultaneously the requirements for transit conditions with full or reduced power, often at constant propeller RPM, must be fulfilled.

In all the cases it is desired that no harmful cavitation phenomena appear (i e no erosion and vibration problems and no propeller force reduction).

Investigations in the SSPA cavitation tunnel and towing tank have been carried out with a number of propeller and duct models to study the influence of geometric parameters on the propeller behaviour at different conditions. Some of the results of these investigations are analysed and discussed here.

NOMENCLATURE

C	Chord length
D	Propeller diameter
F	Maximal profile mean line camber
F_S	Towing force
g	Acceleration due to gravity
H	Position of propeller shaft center below water surface
J	Advance ratio = V_A/Dn
K_P	Pressure pulse coefficient = $2\Delta p/\rho D^2 n^2$
K_T	Propeller thrust coefficient = $T_P/\rho D^4 n^2$
K_{TD}	Duct thrust coefficient = $T_D/\rho D^4 n^2$
K_{TT}	Total thrust coefficient $(T_P + T_D)/\rho D^4 n^2$
n	Rate of revolutions
p_o	Static pressure at the propeller surface
p_v	Vapour pressure of water
$2\Delta p$	Pressure fluctuation amplitude
P	Propeller pitch
Q	Propeller torque
R	Propeller radius = D/2
r	Radius
R_S	Hull resistance
R_n	Reynolds number for the propeller model $= \frac{C0.75R\sqrt{V_A^2 + (0.75\pi Dn)^2}}{\nu}$
S	As index ship
t	= Thrust deduction factor = $(T_S - R_S - F_S)/T_S$
T_P	Propeller thrust
T_D	Duct thrust
T_S	Total thrust for ship
V	Speed
V_A	Speed of advance
w	Wake fraction = $(V - V_a)/V$
γ	Weight by volume
ν	Kinematic viscosity of water
ρ	Mass density of water = γ/g
σ_n	Cavitation number = $(P_o + \gamma H - P_S)/\sigma/2(nD)^2$

INTRODUCTION

The problems associated with the design of multi-purpose CP-propellers have been discussed in a number of papers in connection with tugs, icebreakers, fishing and offshore supply vessels, see references [1], [2] and [3].

The present observations and analysis are the results of investigations carried out in the SSPA cavitation tunnel and towing tank. The open water tests with ducted propellers have been carried out in the high speed test section of the cavitation tunnel to obtain the highest possible Reynolds number [4]. The cavitation studies were carried out with the propeller units working behind complete hull models in the large test section (beam = 2.6 m, height = 1.6 m) of the cavitation tunnel [5].

PROPELLER DESIGN

The main parameters of the propeller are diameter and pitch. A large diameter is usually advantageous at bollard conditions, but this quantity is often restricted by the lack of space. To obtain a high tow rope force at bollard in spite of a restricted diameter the application of an accelerating duct around the propeller will be advantageous. The relations between conventional and ducted propellers with regard to optimal thrust diameter at a given machinery (power and RPM constant) appear from Fig 1.

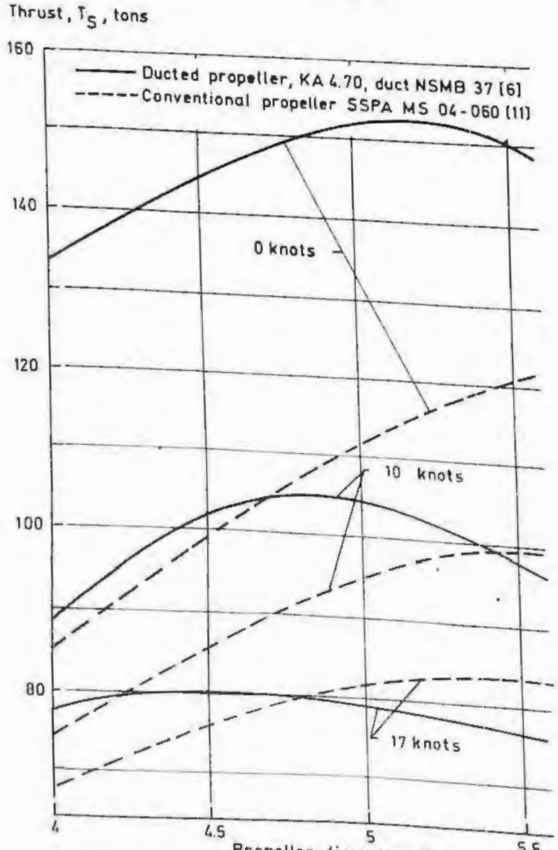


Fig. 1 Relation thrust-diameter for ducted and conventional propeller at 9 MW and 140 RPM

For a fishing vessel with a CP propeller it was proved that a reduction of the propeller diameter by cutting the blade tips and application of a suitable duct improved the efficiency mostly at low speed trawling, but also at the transit condition, Fig 2.

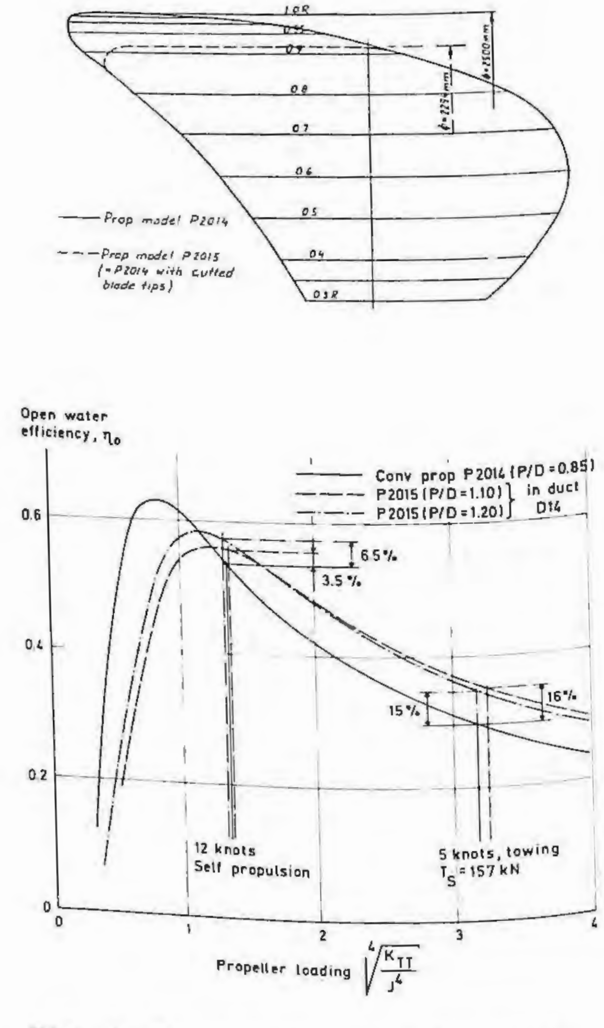


Fig. 2 Increase of propeller efficiency on a fishing boat by blade tip cutting and duct application.

The desired (maximum) rate of revolutions and power could be constantly absorbed at different ship speeds by adjusting the pitch. The required pitch is obtained by turning the propeller blades giving the same change of pitch angle for all the radii. The radial pitch and thus the loading distribution will therefore be significantly deformed at off-design conditions, Fig 3. This fact disfavours the CP-propellers in relation to FP-propellers when backing.

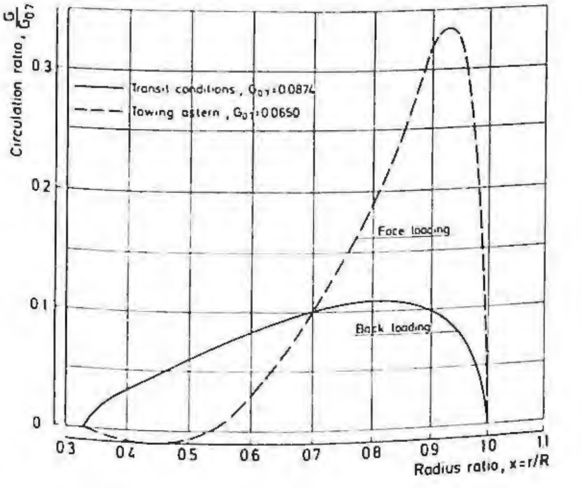


Fig. 3 Radial loading distribution for a CP-propeller at transit ahead and towing astern conditions.

The shape of the blade form is usually determined by the cavitation properties. To obtain sufficient margin against eroding and force reducing cavitation at off-design conditions and especially at backing, a Kaplan-type blade is usually recommended.

The blade section mean line camber is also an important parameter. At the choice of this parameter the different operation loadings must be appraised and the design will be a compromise between the different requirements.

DUCT DESIGN

In order to obtain good backing performance a duct shape identical or similar to the NSMB duct No 37 is usually used, as this duct has been proved advantageous at backing [6].

Caster [7] systematically varied the duct ratio by increasing the duct profile inclination to find the optimal shape for backing. In spite of obtaining deteriorating backing properties with increased duct ratio he never investigated any ducts with further reduced duct ratio.

The backing performance of these ducts was, however, only investigated with FP-propellers. According to Professor Dyne [8] the shape of the duct is connected to the radial loading distribution of the propeller. The loading distribution of a backing CP-propeller was estimated, Fig 3, and the corresponding duct calculated according to Dyne's theories. It was found that the diffusor angle for the backing propeller (i e duct ratio at ahead conditions) ought to be much smaller than on duct 37, Fig 4. In order not to deteriorate the ahead thrust too much a compromise with somewhat reduced duct ratio is proposed. This duct is according to reference [9] expected even to slightly improve the ahead efficiency. For different reasons this duct has so far not been investigated.

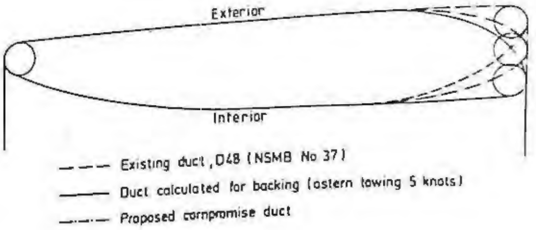


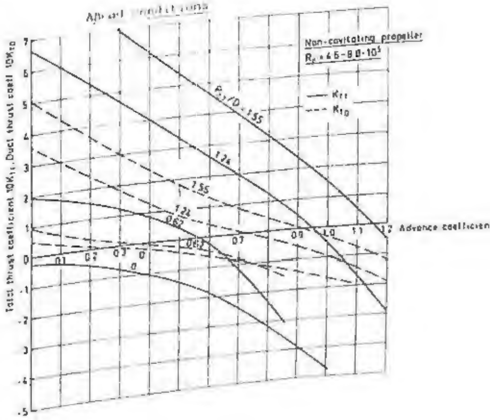
Fig. 4 Duct shape for backing CP-propeller.

Investigations with navy tugs show that the backing thrust at bollard is reduced when the duct profile thickness is increased, whilst this parameter must be kept as low as possible within the limits of the strength requirements.

EFFICIENCY

The efficiency of the ducted propeller is when running ahead superior to that of a conventional propeller at high loadings (towing at low and moderate speeds). At lower loadings (higher advance ratios) the duct thrust turns negative and works contrary to the propeller thrust, Fig 5.

At backing the duct thrust works in the same direction as the propeller thrust only at very low and zero speeds, Fig 5.



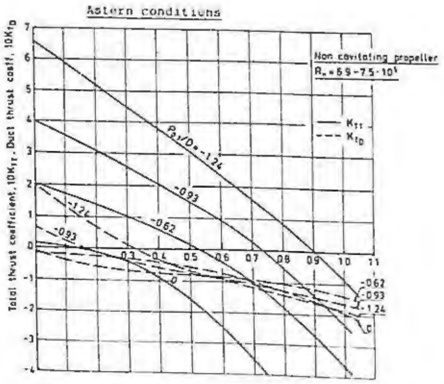
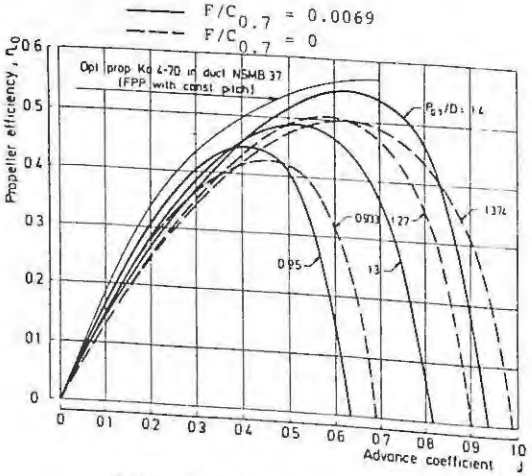


Fig. 5 Total and duct thrust coefficients for ahead and astern working CP-propeller.

If the propeller design is adapted to the transit conditions ahead a very deformed loading distribution is obtained at backing. This design also gives rather cambered propeller profiles, also disadvantageous for backing, Fig 6.

Ahead conditions



Astern conditions

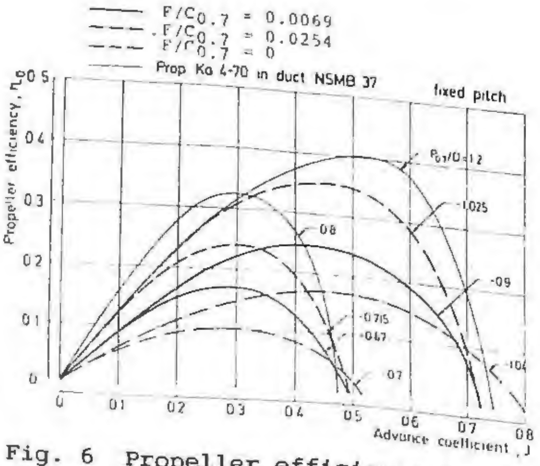


Fig. 6 Propeller efficiency for ahead and astern working CP-propeller.

MERIT COEFFICIENTS

The influence of the profile camber ratio, F/C, on the bollard ahead and astern properties indicated by the merit coefficient, $K_{TT}/(K_Q)^{2/3}$, appears from Fig 7.

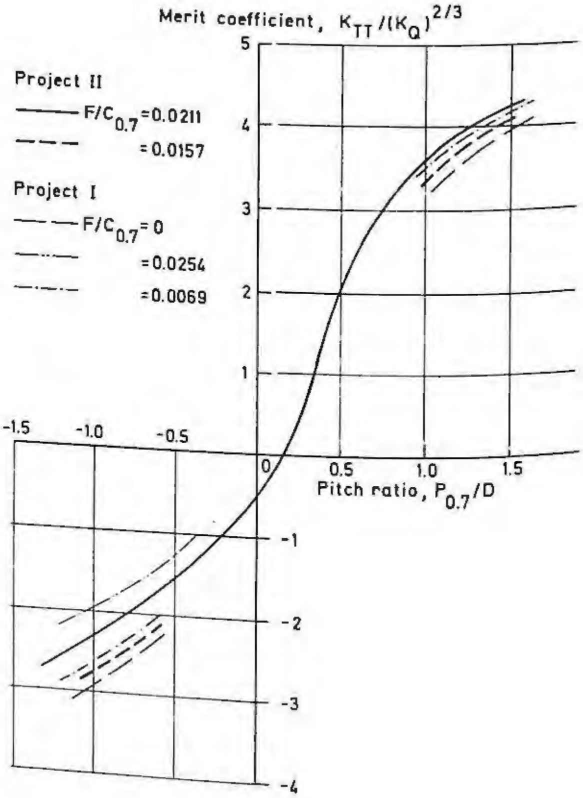


Fig. 7 Influence of propeller pitch and profile camber on the merit coefficient at bollard condition.

In Fig 8 the total thrust coefficient at bollard conditions is plotted against the profile camber ratio for constant power and RPM. From this figure it can be noticed that the improvement of the backing properties when reducing the profile camber is larger than the corresponding deterioration of the ahead properties.

The reduction of the profile camber may, however, give unsatisfactory cavitation performance at other loadings, see below.

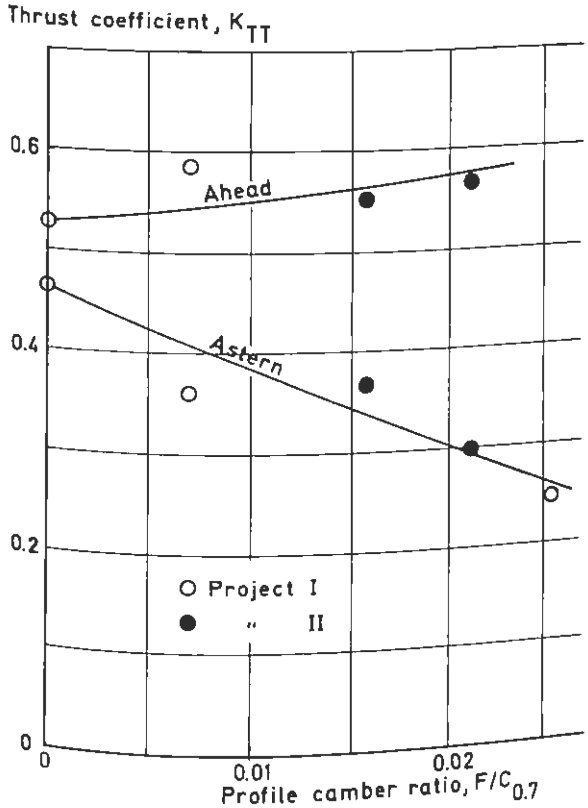


Fig. 8 Influence of profile mean line camber on ahead and astern thrust coefficient at bollard conditions.

PROPELLER-HULL INTERACTION

The above notations are referred to open water test results.

When the ducted propeller is located behind the ship one can permit fairly extensive integration between the hull and duct without reducing the bollard thrust, as observed from open water tests.

The interaction factors (wake fraction, thrust deduction factor, relative-rotative efficiency) at self-propulsion are more influenced by the shape of stern and duct hull connection.

According to comparative studies in the SSPA towing tank the presence of the duct itself does not significantly influence the propeller hull interaction factors.

The influence of the ship speed and propeller loading on the thrust deduction factor is shown in Fig 9. The relations correspond well to those obtained by Harvald [10] for conventional propellers.

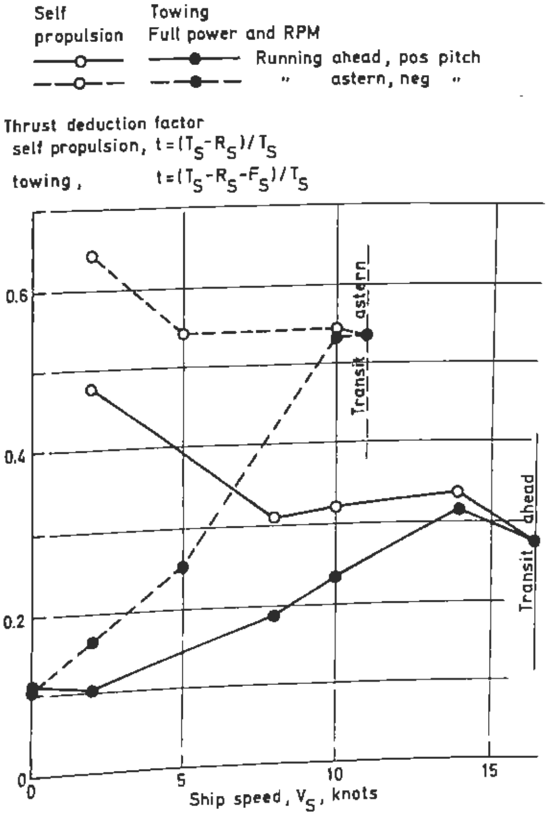


Fig. 9 Thrust deduction factor at different conditions.

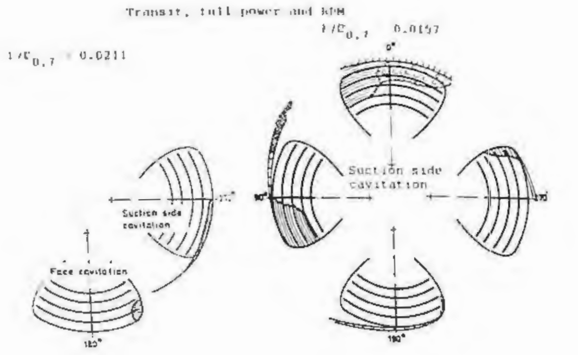
CAVITATION AND VIBRATION

At the choice of the propeller design point the cavitation properties must be carefully analysed.

If the propeller is designed optimal for the transit condition the performance at backing will be disadvantageous both with regard to efficiency (see above) and cavitation. The face (pressure side) cavitation on the propeller blades at bollard astern will be more extensive and may cause erosion on the blades and inside the duct and also propeller force reduction.

The present type of propulsion units is often combined with a multi-motor system and it may therefore be possible that the propeller will run at reduced power but full RPM when one or more motors are shut off. At this loading face cavitation appears at the leading edges of the propeller sections, especially when highly cambered, Fig 10.

If the propeller design is more adapted to towing at low speeds less profile camber cavitation is achieved and the bollard astern will be reduced as well as the face cavitation at reduced power and full RPM ahead, Fig 10.



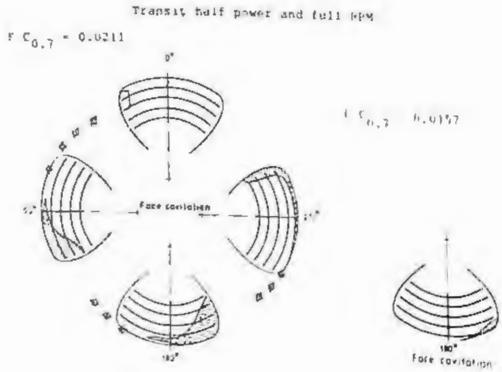


Fig. 10 Cavitation patterns at transit conditions.

However, the back (suction side) cavitation at the transit conditions will increase, Fig 11, and in some cases cause force reduction at cavitation numbers of current interest, Fig 12.

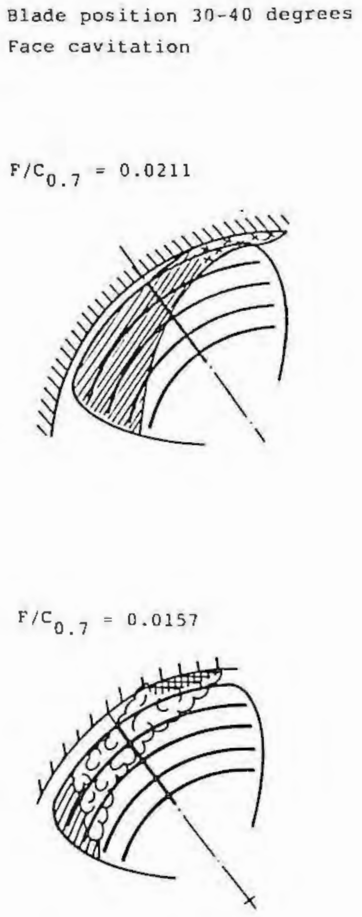


Fig. 11 Cavitation patterns at bollard astern conditions.

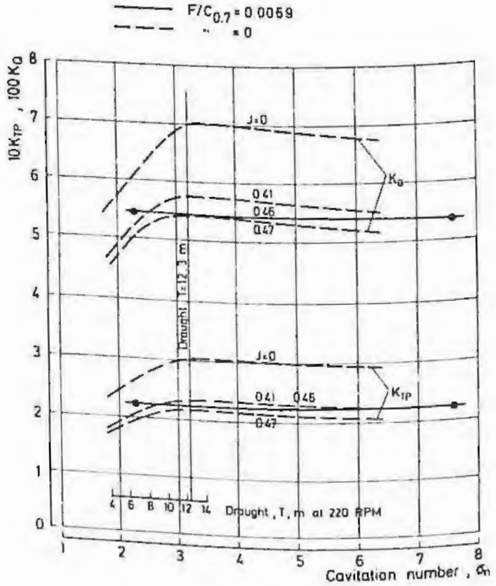


Fig. 12 Influence of profile mean line camber on force reducing cavitation.

The propeller induced pressure pulses on the hull connected with cavitation are due to the duct usually rather small. At very low and zero speeds propeller-hull-vortex (PHV) cavitation may appear and cause very high local pressure fluctuations, Fig 13. If a twin screw arrangement has propulsion units very close to each other a vortex between the propeller tips can be created. This type of cavitation will disappear as soon as the ship speed rises.

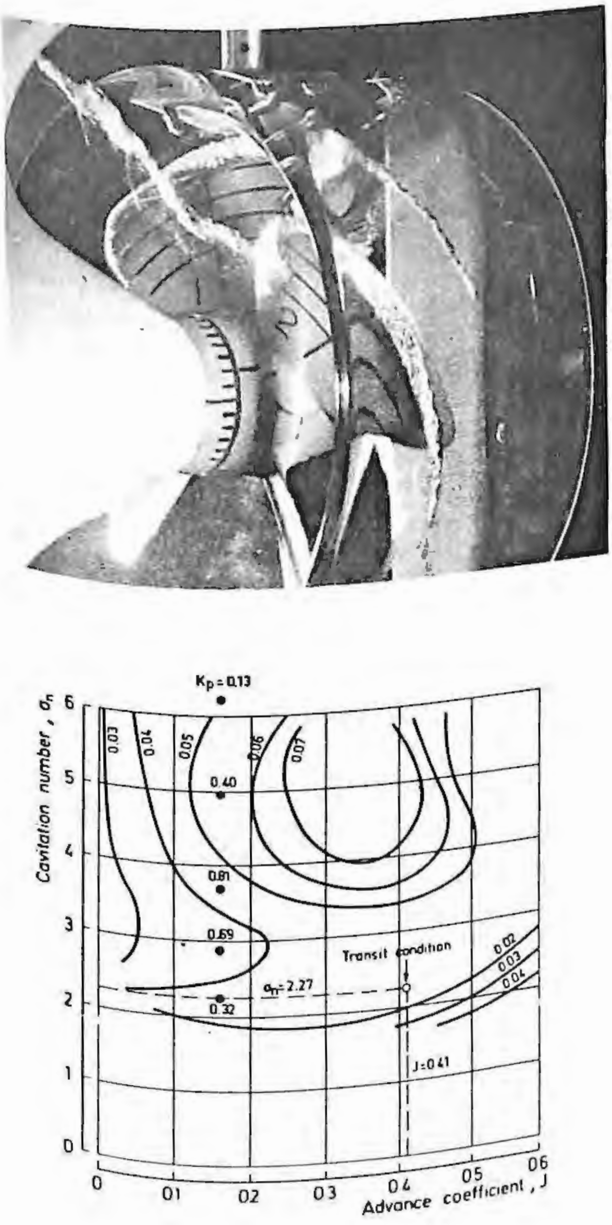


Fig. 13 PHV cavitation, cavitation patterns and pressure pulses.

CONCLUSIONS

Multi-purpose ducted CP-propellers can be advantageous as they make good use of the machine power available, transforming it to a high thrust and tow rope force.

The loadings for operation must, however, be known before the design of the propulsor, which thus must be a compromise between the different operational loadings. Possibly also the choice of the duct shape must be a compromise.

The propulsion unit must be carefully investigated at all the loadings of current interest both with regard to efficiency and cavitation properties, so that undesired phenomenon do not appear.

In some cases, if the space and strength requirements permit, azimuth thrusters may be more advantageous than the fixed ducted CP-propeller as they are designed for only one thrust direction.

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