SCALE EFFECTS ON THRUST DEDUCTION FACTOR

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CONTENTS

1 INTRODUCTION
2 BASIC CONSIDERATIONS
3 POSSIBLE CAUSES OF SCALE EFFECTS ON THRUST DEDUCTION FACTOR
3.1 PROPELLER SCALE EFFECTS
3.2 LOAD COEFFICIENT EFFECT
3.3 ROUGHNESS SCALE EFFECT
3.4 WIND EFFECTS; SEA CURRENTS
3.5 WALL EFFECTS
3.6 MEASUREMENT ERRORS
4 SOME COMMENTS ON RESULTS OF VICTORY TESTS
REFERENCES

SYMBOLS

A_o - PROPELLER DISC AREA
C_{Th} - PROPELLER LOAD COEFFICIENT
Δp - PRESSURE JUMP AT PROPELLER DISC
R - TOTAL RESISTANCE OF SHIP
R_e - REYNOLD'S NUMBER
t - TOTAL THRUST DEDUCTION $t = t_d + t_f + t_w$
t_d - DISPLACEMENT THRUST DEDUCTION
t_f - FRICTIONAL THRUST DEDUCTION
t_w - WAVE THRUST DEDUCTION
T - PROPELLER THRUST
V - SHIP SPEED
W - TOTAL WAKE
W_d - DISPLACEMENT WAKE
W_f - FRICTIONAL WAKE
ρ - MASS DENSITY OF WATER
r - REAL FLOW

1 INTRODUCTION

The study of possible scale effects on thrust deduction factor is of considerable practical importance and it is mentioned since 1935. In recent years the problem has been discussed in several papers and conferences but the question is far from decided, essencially as consequence of gaps in the knowledge of the mechanism of the flow phenomena. However, a historical review shows that the general idea of the scale effect on thrust deduction has changed.

2 BASIC CONSIDERATIONS

To begin with it is appropriate to present some fundamental concepts with interest to the further development of our subject.

The complex hull propeller interaction has influence in propulsive efficiency, vibration, cavitation and turning, and it is characterized by three important parameters : wake fraction, thrust deduction fraction and relative rotative efficiency.

The thrust deduction factor t can be defined as the ratio $R/_T$ where T represents the propeller thrust and $R = T - R$ the augment of resistance caused by the suction over the rear part of the ship. This suction is due to the action of propeller which increases the flow velocities along the rear part. The static pressures decrease and the shear forces increase.

Helmbold introduced the use of principle of super position dividing the thrust deduction factor t into three components :

t_d - displacement thrust deduction (this designation is preferable than potential thrust deduction)

t_f - frictional thrust deduction

t_w - wave thrust deduction

The complex interaction between each component is assumed to be small. It was found that in general the two later components are negligible when compared with t_d.

A negligible wave thrust deduction means that the generation of ship waves is only slightly influenced by a working propeller. This fact is not obvious but it is supported by some experiments (Janes, Amtsberg). However this fails for high loaded propellers. One way to assess t_w would be to evaluate the difference in t between a surface model and a corresponding double model tested at a non-wave-making depth with same speed and propeller load. As it seems that there are no available results about such kind of experiments and there is a lack of knowledge on t_w, the approach that this component can be neglected will be assumed. This can be a good assumption when speeds are below significant wave making.

A negligible frictional component means that due to a working screw the increase in viscous resistance all over the ship (mainly on rudder and stern parts forward of the screw-points close to separation regions) is small. As the part influenced by the propeller is relativelly small, the increase of local shear forces seems not to be important relatively to the strength of the total shear force. This fact was confirmed by calculations of the frictional thrust deduction t_f (Dickmann, Hucho) and by experimental measurements (Amtsberg; The National Physical Laboratory). The maximum value found was about $t_f \simeq .02$.

From the above it seems that the main part of the thrust deduction factor appears to be due to the displacement component t_d and the scale effect on t essencially concerned with the relation between t_d for full scale and t_d from model.

The potential or, preferably, the displacement thrust deduction t_d is caused by the decreased pressure along the rear part of a double model representing the ship and depends mainly upon the hull form and thickness and the distribution of the boundary layer along the hull.

3 POSSIBLE CAUSES OF SCALE EFFECT ON THRUST DEDUCTION FACTOR

3.1 PROPELLER SCALE EFFECTS

The study of propeller scale effects is a strong need since this appears to be the most important factor on t scale effect.

As referred before we are going to consider the problem of scale effect on t as essentially a problem of scale effect on t_d.

It is well known that a screw propeller does not operate in a homogeneous pressure and velocity fields. On the other hand the propeller changes the flow along the hull by increasing or decreasing the separation areas, by changing the formation of bilge vortices and other similar effects.

The existence of those stern bilge vortices is not considered in theorie. In general, if during towing tests the flow separates from the hull ahead of the propeller, the separation area will decrease due to favourable action of the propeller. It is difficult to conclude what is the influence on t. But if during towing tests separation occurs over and behind the propeller, now the separation areas, effective resistance and w_{dr} (displacement wake for real fluid) will increase. From this we can conclude that the thrust deduction will increase too.

The above is one explanation of the differences between t_{dr} and $t_{experimental}$ since when theory is used it is assumed that the propeller influences the flow around the hull in the same way as in ideal flow conditions. The stern bilge vortices are not considered in theory too.

Other factors about the difference between t_{dr} (from theory) and $t_{experimental}$ can be pointed to. For instance, one can refer the influence of the frictional thrust deduction. The magnitude of propeller scale effects is unknown and the present knowledge about the phenomena is not enough.

If the inequality between the flow along the stern of a towing model and a self propulsion model (for the same vessel) is not very marked, t_{dr} (real flow) can be evaluated using, for instance, a formula developed by WALD, from momentum considerations (1) :

$$t_{d_r} = \frac{\int 2\, w_{d_r} \frac{e_r}{v}\, d\,(A/A_o)}{C_{T_h}}$$

where

$$\frac{e_r}{v} = -(1-w_f) + \sqrt{(1-w_f)^2 + \frac{\Delta p}{1/2\, \rho\, v^2}}$$

As we can see t_{d_r} is given as a function of the propeller load coefficient, w_f and w_{d_r}.

From Simon Bolivar and a 150,000 dwt tanker tests it was found that $t_{d_r} < t_{experimental}$. This is in agreement with SSPA calculations (Swedish State Shipbuilding Experimental Tank) which found w_{d_r} independent of scale.

3.2 LOAD COEFFICIENT EFFECT

Some overload tests show an interaction between this propeller parameter and t.

For instance, models of Japanese tankers K. MARU and N. MARU were tested with two sets of propellers. The results show a scale effect but no definite conclusions were reached.

Let's define a propeller load coefficient C_{Th} as

$$C_{T_h} = \frac{T}{1/2 \, \rho \, A_o \, v^2}$$

where A_o is the propeller disc area and v the ship speed.

The sketchs presented in fig. 1 represent possible stream-lines around a ship's hull in the horizontal plane of a propeller axis, working in an ideal two dimensional flow.

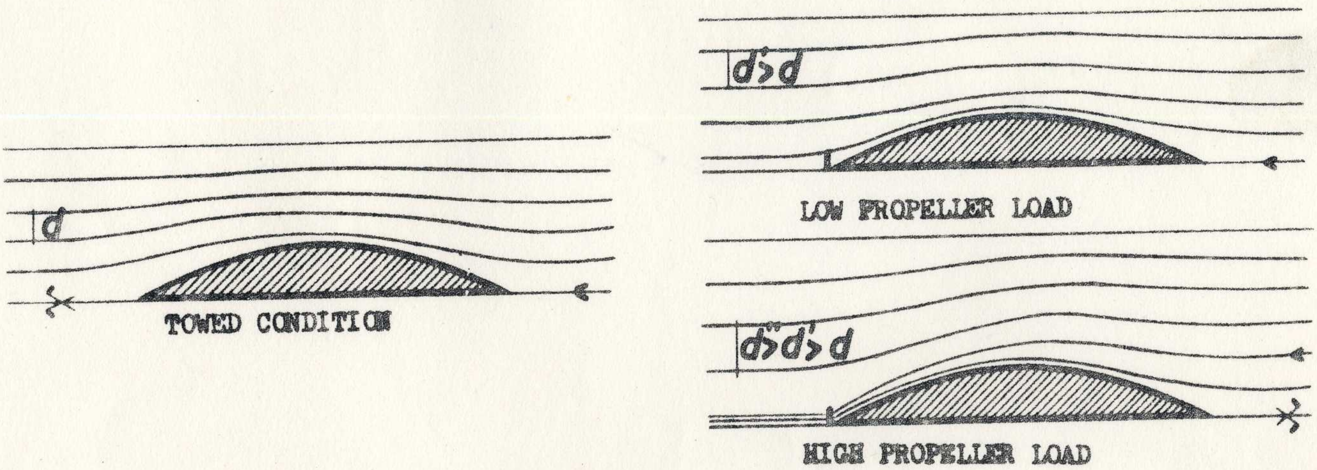

fig 1

From measurements, calculations (SSPA) and approxi mate methods (Dickmann) it seems that the value of w_{d_r} should be between w_{d_i} and $w_{d_i} \times (1-w_f)$, where w_{d_i} is the displacement wake in ideal flow and w_f the frictional wake.

For bodies of revolution, if we suppose the first relationship $w_{d_r} = w_{d_i}$, then t_{d_r} is greater than t_{d_i} for all propeller loadings.

However for the relation $w_{d_r} = w_{d_i} (1-w_f)$, $t_{d_r} = t_{d_i}$ for lightly loaded propellers ($C_{T_h} \longrightarrow 0$) and t_{d_r} is lower than t_{d_i} for more heavily loaded propellers.

3.3 ROUGHNESS SCALE EFFECT

The non consideration of this effect can be a crude assumption. As part of the Victory programme (experiments on Victory ships and models) some investigations were made to determine the influence of roughness on t. From Victory and Simon Bolivar tests it was found that t, was diminished by roughness and this tends to decrease the scale effect (if t increases with scale).

For instance, the first referred tests showed that t decreases from .27 (smooth ship) to .22 (roughned boat).

DOVE (Admiralty Experiment Works) used different roughning models to change the boundary layer. He concluded that thrust deduction was not altered by resistance coefficient.

There is a lack of knowledge about this effect and a new defenition on t have been proposed :

$$t^{*} = \frac{T_{rough} - R_{rough}}{R_{smonth}}$$

3.4 WIND EFFECTS ; SEA CURRENTS

These factors also need deeper study. Tests carried out several years ago proved that one can assume that thrust deduction factor does not change as a result of the slight overload caused by the wind.

3.5 WALL EFFECTS

This is a problem that can distort the results of bigger models. Based in additional wall effect tests, eventual corrections need to be introduced.

It is possible that some of the Victory tests results were affected by wall effects, but this possibility has not been fully analysed.

3.6 MEASUREMENT ERRORS

Some authors (Manen, Hadler) admit the possibility of important experimental errors in their experiments. Hadler gives $\pm$ 5% error in his measurements. For other tests an idea of the amplitude of errors is not available.

The defenition of t as $\frac{T - R}{T}$ leads to a relative error in t that is greater than the error in $R/_{T}$.

The magnitude of the scale effects seems to be smaller than the measurement errors.

Improvements on measuring techniques with better dynamometers, torsionometers and so on are expected.

4. SOME COMMENTS ON RESULTS OF VICTORY TESTS

Several series of experiments have been carried out at NSBM (Netherlands ship model basin) with the Victory model family. The main objective of those experiments was. to investigate the possibility of to find an extrapolation method between the measured data (from an individual model) and the ship. The largest model was a 22.5 m motor boat.

Values of thrust deduction factor against Reynolds number are plotted in figure 2.

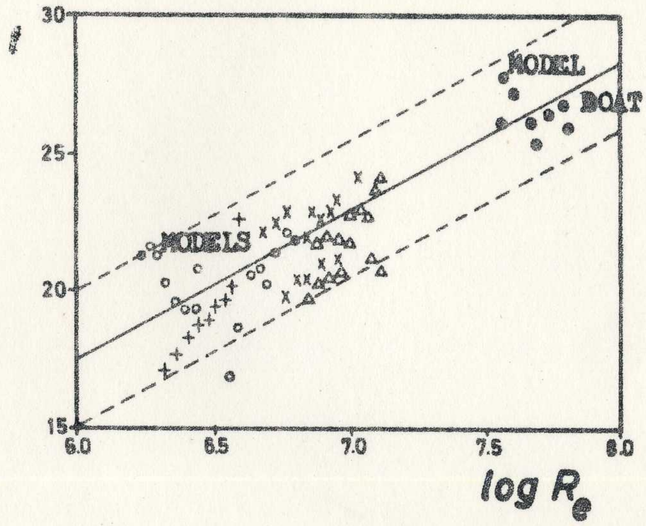

fig 2

Whereas one can note a very scattered set of values, the following approximate relationship has been proposed,

$$t = -0.151 + 0.0542 \log R_e$$ (loaded condition at even Keel)

which shows that t increases rapidly with the increase of Reynolds number.

This result was confirmed by model and full scale tests with the U.S.S. ALBACORE. Unfortunatly, due to security reasons full results are not available for the submarine. The measurements were also difficult.

However, Lindgren with a similar serie of models, concluded that t decreases with R_e.

The results from tests with Victory models (NSBM) show a marked variation of t with speed, as sketched in fig. 3.

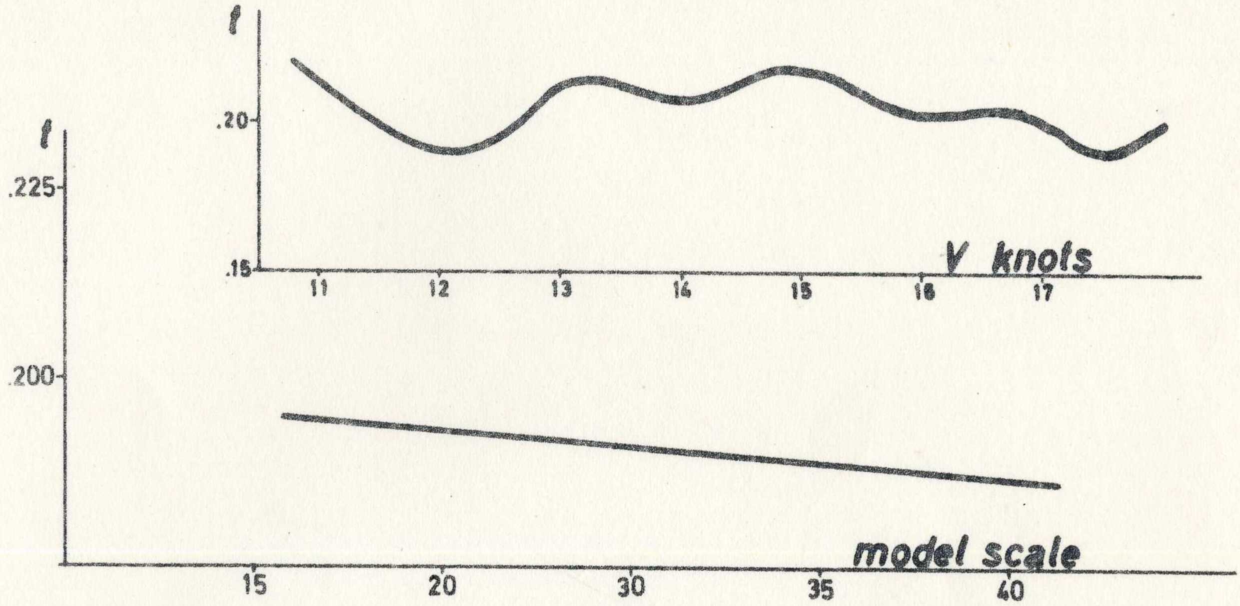

fig 3

Results published by the Swedish State Shipbuilding Experimental Tank, concerned with form Victory geosims, give smaller value of t for higher R_e which is in contradiction to results obtained from Dutch trials. Different propeller diameters were used in both experiments, so the values of dynamic load coefficient could be different. Particular attention was paid to measuring techniques in the latter trials.

Some reasons can be suggested to explain why the theoretical results of reference (1) do not predict the scale effect on t found in Victory tests :

— all theoretical computations are based in basic assumptions that could not represent the truth.

— large Victory model results could be influenced by wall effects (however, the model boat was tested at sea)

— measurement errors

— flow instabilities

— propeller scale effects

—••—

It is a fact that results are conflicting and theory contradicts some of them.

It seems that the alarming trend with regard to scale effects on t, intimated with the Victory tests is more or less accidental.

The scale effects seem to be significant only for those situations where the propeller can change the flow along the stern considerably.

REFERENCES

1. DYNE, G. "On the scale effects on thrust deduction"
TRANSRINA 1973

2. VAN LAMMERAN, W.P.A. "Scale effect experiments on Victory ships and models"
TRANS INA 1955

3. LINDGREN, H. "The correlations of ship power and resolutions with model test results

4. BENEDEK, Z. "An investigation of the scale effect on self-propulsion factor"

5. BEVERIDGE, J. "Analytical prediction of thrust deduction for submersibles and surface ships"

6. KORVIN, B. "Stern propeller interaction with a streamline body of revolution"

7. TSAKONAS, S. "Analytical expressions for thrust deduction and wake fraction for potential flows

8. BROWN, D.K. University College London
M. Sc. Notes

9. WEINBLUM, G. "The Thrust deduction"