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# NAVY DEPARTMENT
## THE DAVID W. TAYLOR MODEL BASIN
### WASHINGTON 7, D.C.

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by

A. J. Tachmindji

Prepared for the American Towing Tank
Conference, to be held in Washington, D.C.,
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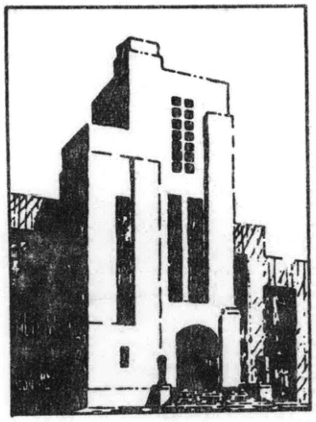

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## Introduction

A number of attempts have been made lately[1*] to duplicate in propeller tunnels the wake discontinuity behind a vessel and to investigate the effects of such wake pattern on the cavitation inception speed. Such an approach, no doubt, improves the correlation between model and full scale propellers when operating in a variable inflow field. The presence of radially and circumferentially varying wakes will produce a decrease of the inception speed of cavitation and allow the study of the cavitation pattern when each blade is subjected to a different inflow velocity. Propeller tunnels, therefore, equipped with such flow regulators should improve the cavitation similarity between model and full scale, particularly in the case of single screw vessels where large velocity gradients are present.

The presence of a varying wake does, however, complicate the problem of cavitation scaling. An attempt has been made at DTMB to understand the phenomenon of model and full scale cavitation correlation by investigating the simpler case of a propeller operating in practically uniform inflow. An understanding of this mechanism and the effects that may influence the cavitation pattern in the full scale propeller should indicate the critical areas to be investigated on model scale. Furthermore, observations of full scale propellers would in themselves produce information regarding the variation in cavitation pattern and the parameters that may affect it.

For this purpose, observations and photographs were made of a full scale propeller through glass ports located in the stern of the vessel. Photographs were obtained for each blade at angular positions of ten degrees over the part of the circumference which was visible and for the complete speed range. Comparative

* Numbers indicate References on page 7.

tests were conducted in the 24" Variable Pressure Tunnel with a model having a linear ratio of nine and operating in uniform inflow. The model was tested with water at saturated air content and at speeds equal to the actual full scale speeds. Variations above and below these speeds showed no change of the cavitation pattern.

This discussion will be limited to a comparison of face cavitation inception, its extent and the parameters that may affect it.

## Comparison between model and full scale

The vessel chosen for this investigation is one giving small wake variations over the propeller disc. The full scale propeller is assumed to be operating in a wake distribution which can be determined from model tests by measuring the nominal wake in the propeller plane without the propeller working. The longitudinal and tangential wake fractions (the latter measured negative in the direction of propeller rotation) are shown on Figures 1 and 2. It is noted that the magnitude of the longitudinal component is small, but the effect of the tangential wake is certainly not negligible. The difficulty of duplicating the tangential velocity in the tunnel indicated the need for a model comparison with uniform inflow.

The areas of face cavitation for both model and full scale propellers operating at equivalent conditions are shown on Figures 3 to 6 for ship speeds expressed as a ratio to the inception speed on the model. By means of marking-strips on the blades of the full scale propeller and analysis of all the photographs it has been possible to indicate the areas for which face cavitation is present. Figure 7 shows the area of face cavitation for different blade positions measured upwards from the vertical. The extent of face cavitation at any speed is indicated by the intercept between the lines representing contours for different blade positions. For example, at a speed ratio of 1.1 and with the blade at the $60^{\circ}$ position, face cavitation existed on the full scale propeller between x= 0.52 and 0.96, while in the equivalent condition for the model the cavitation area extended from 0.63 to 0.86.

Certain features are immediately noted from the full scale observations. The extent of cavitation is not a direct function of speed but may actually decrease locally with increasing speed. The hollows in the contours at speed ratios of 1.42 and 1.72 for all three blade angles correspond to the hollows in the resistance curve. It is, therefore, apparent that the extent of cavitation is very critically affected by both the power and the wave formation over the propeller. Such an effect is of course expected but it only emphasizes the critical character of cavitation and the effect that relatively minor changes have on cavitation inception.

The presence of these hollows is probably due to a combination of effects:

(a) Change of the total thrust delivered by the propeller.
(b) Change of the radial distribution of circulation.
(c) Variation in the immersion of a particular section due to change in wave profile.
(d) Change of the nominal wake due to the orbital motion in the wave.
(e) Change in the radial distribution of effective wake and thrust deduction.

Although the relative magnitude of these effects is not known it is expected that they would all contribute significantly to changes in the cavitation pattern. It is also noted that for the full scale propeller the area of face cavitation changes significantly with blade angle. This variation can hardly be explained by a change of cavitation index resulting from varying immersion, as this would amount to not more than 4% between the 40° and 90° positions. It can result from the variation in the tangential component of the wake over the circumference. The radial distribution and the total load of the blade will also be affected by the presence of adjacent structure (rudders and struts) as the blade approaches them, thus significantly altering the pressure distribution on the propeller blade sections.

Correlation of the cavitation inception speed between model and full scale can also be obtained from Figure 7. In order to present, however, a more realistic comparison between the critical cavitation indices of the model and full scale propeller sections, corrections have been made to the full scale sections to take account of the presence of the tangential and longitudinal wakes. The critical cavitation pressure was then computed for both the model and full scale sections on the assumptions that the wake distribution measured on the ship model applies to the full scale vessel and that adjacent structure does not influence the pressure distribution of the propeller sections.

In order to correlate results for the various radial sections having a different amount of camber, the computed critical pressures were used to determine the critical cavitation index for an equivalent symmetrical section which develops lift from angle of attack only. The results are presented in Figure 8 for a symmetrical NACA 66-006 section. The solid line represents the theoretical variation of critical cavitation index with angle of attack below which cavitation will occur. The model results are not too far removed from the theoretical prediction but the full scale values are considerably higher. The dotted line represents the probable limit above which the full scale sections have to operate for no cavitation. It should be emphasized, however, that this probable full scale line should not be considered only due to a scale effect. It indicates an effective cavitation number and includes the effect of parameters which have not been taken into consideration.

This effective critical cavitation index may be considerably different for vessels having large wake variations, small propeller-hull and propeller-rudder clearances and different radial distributions of loading.

## Discussion

The results presented above indicate that face cavitation depend on a number of parameters which in general are satisfied in the mean. It appears, however, that second order effects in those parameters may produce significant changes in the cavitation pattern. What is generally termed scale effect may, to a certain extent, result from our failure to satisfy second order effects.

The similitude of model to full scale is usually based upon a Reynolds number chosen to be greater than a certain critical value and on satisfaction of the cavitation number when referred to the propeller axis. In meeting these two conditions the Froude identity cannot be satisfied, thus the variation in cavitation index with blade position is not similar between model and full scale. The periodic change in static pressure which occurs at each section as the blade rotates is greater for the full scale propeller than for the model. For each element, both the amplitude and the rate of change of cavitation index are different, although its average is equal to that of the full scale propeller section. The error which may arise depends on how the performance of a section varies with a periodically changing cavitation number for the same mean average.

A similar argument can be considered valid regarding the change of cavitation number with speed. Effects of variable immersion due to wave formation, wave orbital velocities and power variations may be significant in the changes they superimpose on the average values.

What is considered probably more important is the effect of the proximity of the hull surfaces to the propeller sections. The pressure distribution of the blade elements will change considerably when the element approaches a fixed surface. For this case, not only will the distribution of circulation along the chord vary with blade position, but the total circulation will also be affected, the magnitude of such effects depending on the propeller clearances.

Tests have indicated that for a propeller operating in uniform inflow the speed of inception of cavitation will be different with and without a rudder present. Furthermore, for a fixed propeller clearance, the variation in pressure distribution will also be a function of the total blade loading.

Additional effects due to air content, Reynolds and Weber numbers are already being investigated.[2,3,4] However, in order to obtain a clear answer to the effect of periodically varying cavitation index and blade loading, tests should be conducted with a simple hydrofoil and not with a complicated assembly of sections represented by a propeller.

Inception of cavitation tests at low air content have indicated a "hysteresis" effect. As the static pressure is reduced, the critical cavitation number is lower than that which would be obtained under increasing pressure. Although such an effect has been reported for non-rotating machinery, it is important to determine whether a similar effect would be present when the cavitation number is changing periodically. Tests of this character should also be conducted on two-dimensional hydrofoils, in order to obtain a better understanding of cavitation scaling between model and full-scale propellers.

## REFERENCES

1 Van Lammeren, W. P., "A Cavitation Tunnel with controllable velocity distribution on the screw disc", SNAME, 1955

2 Strasberg, M., "Undissolved air cavities as cavitation nuclei", N.P.L. Symposium on Cavitation, Sept. 1955

3 Kermeen, McGraw and Parkin, "Mechanism of Cavitation Inception and the related Scale Effect Problems", Trans A.S.M.E., 1955

4 Parkin and Hall "Incipient Cavitation Scaling Experiments for Hemispherical and Ogive - nosed Bodies" Cal. Inst. of Tech. Hydro. Lab. Rep., Dec. 1953

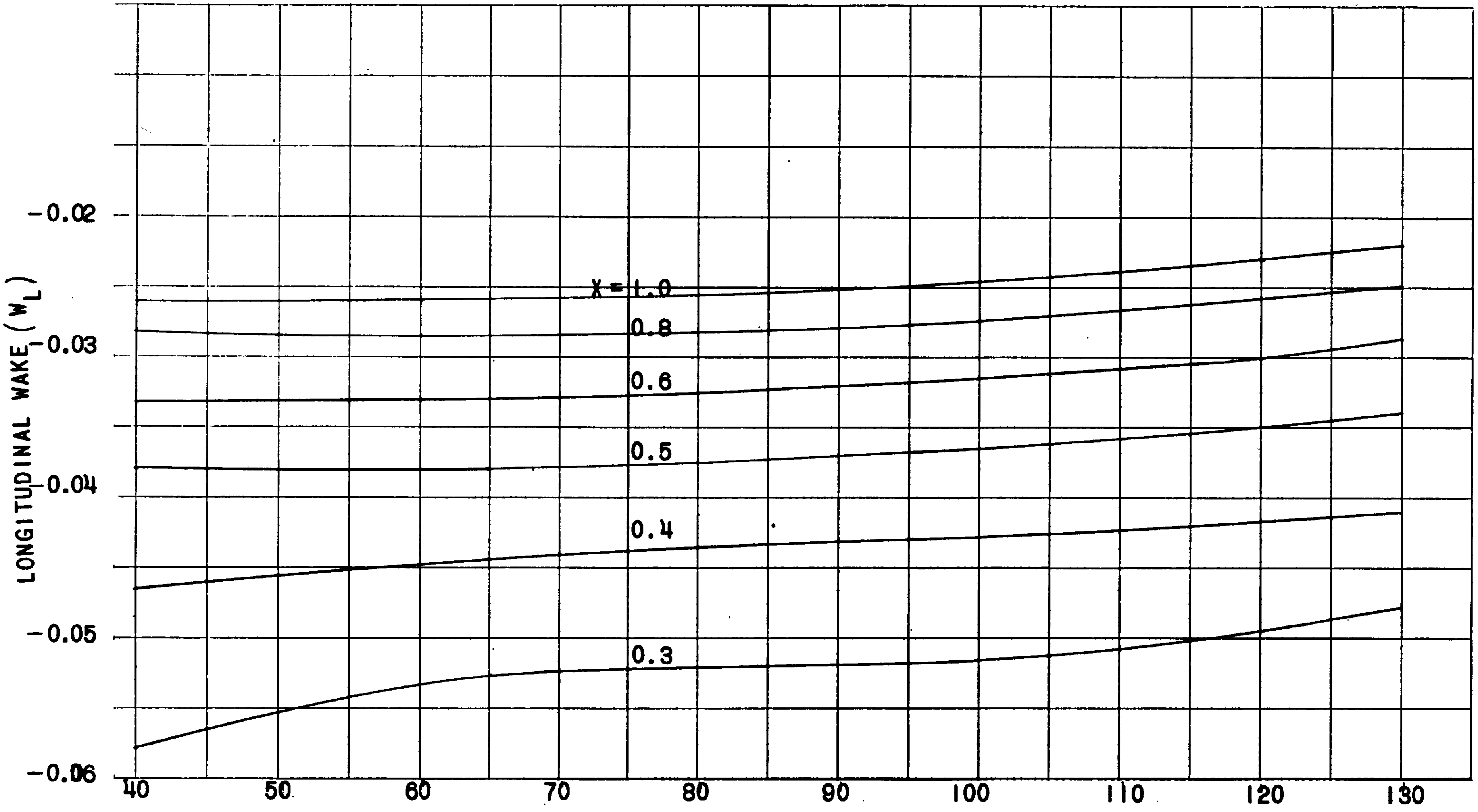
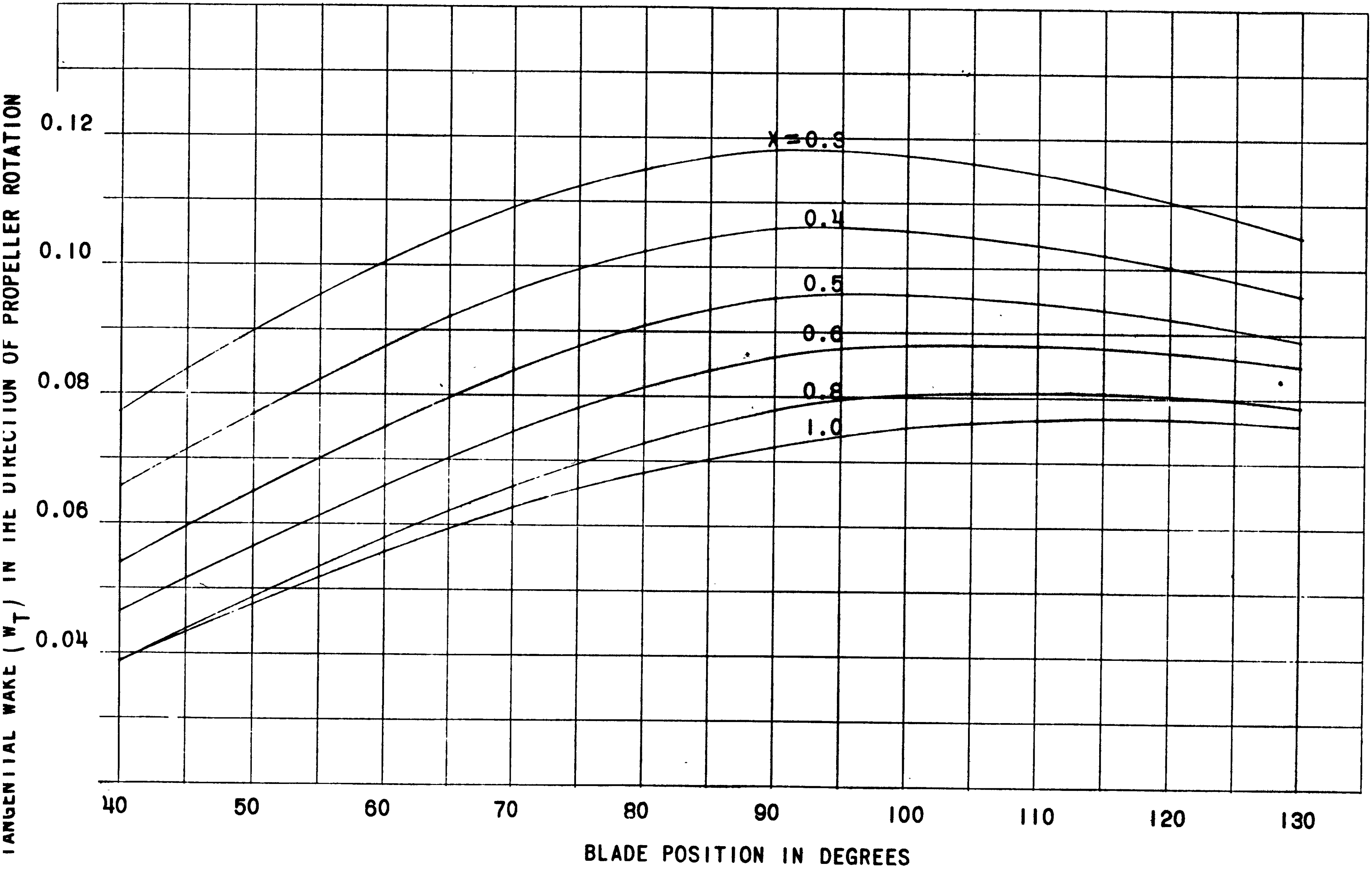


FIG I. LONGITUDINAL WAKE FRACTION


TANGENTIAL WAKE ($W_T$) IN THE DIRECTION OF PROPELLER ROTATION
0.12
0.10
0.08
0.06
0.04
X = 0.3
0.4
0.5
0.6
0.8
1.0
40
50
60
70
80
90
100
110
120
130
BLADE POSITION IN DEGREES

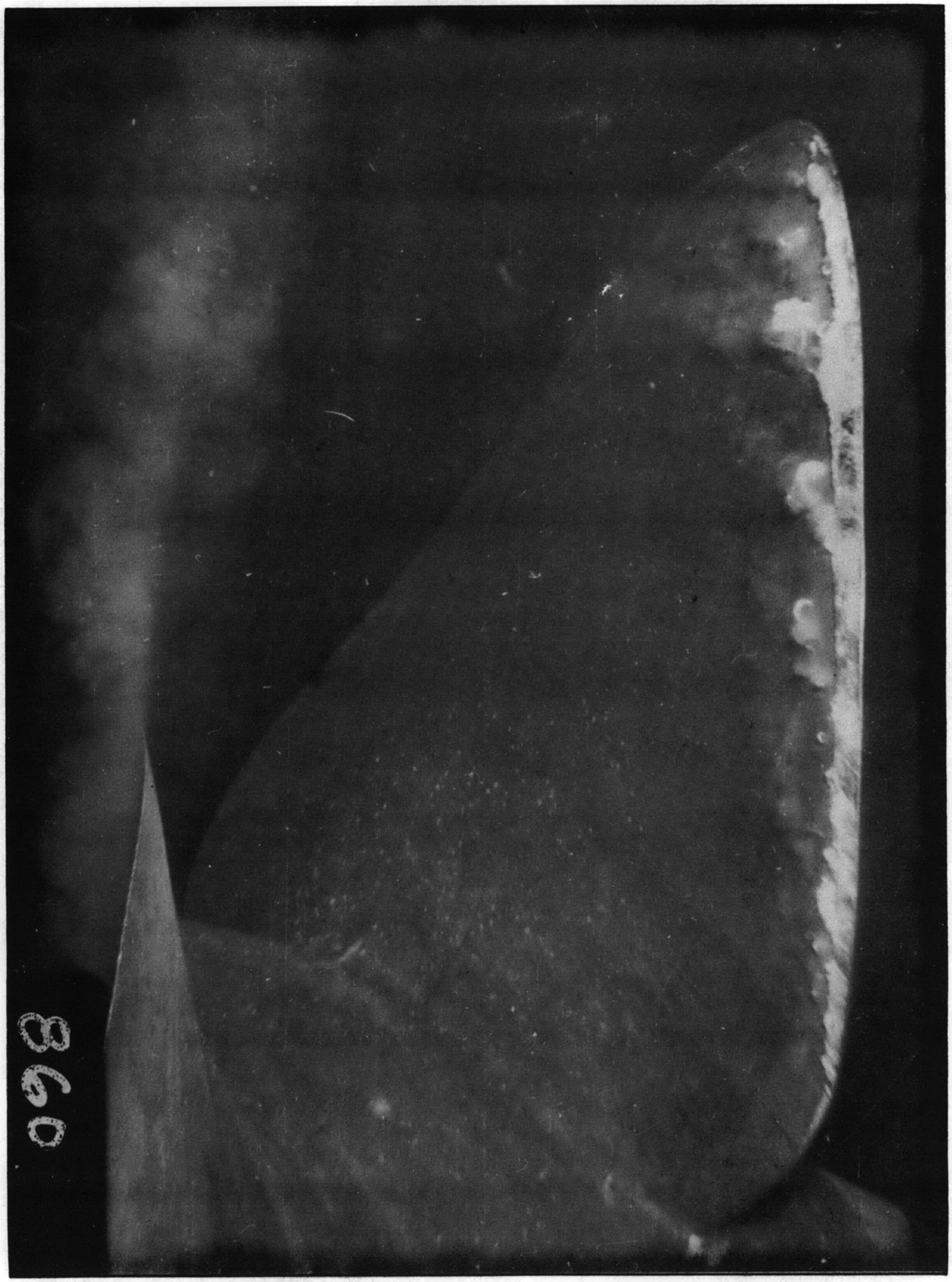


FIG 3. FACE CAVITATION ON FULL SCALE PROPELLER AT $\frac{V}{V_{CR.\ MODEL}} = 1.28$

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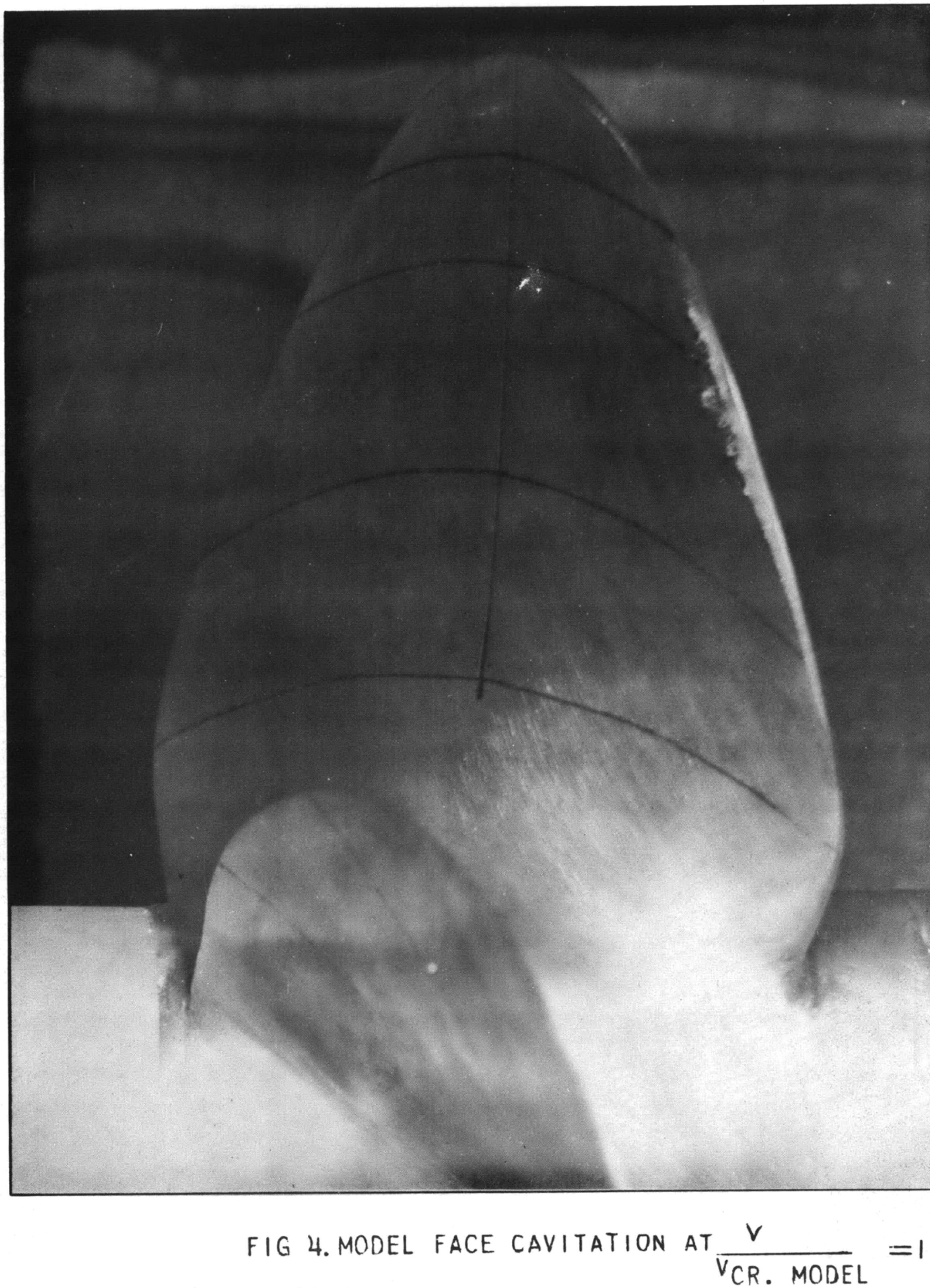

FIG 4. MODEL FACE CAVITATION AT $\frac{V}{V_{CR.\ MODEL}} = 1$

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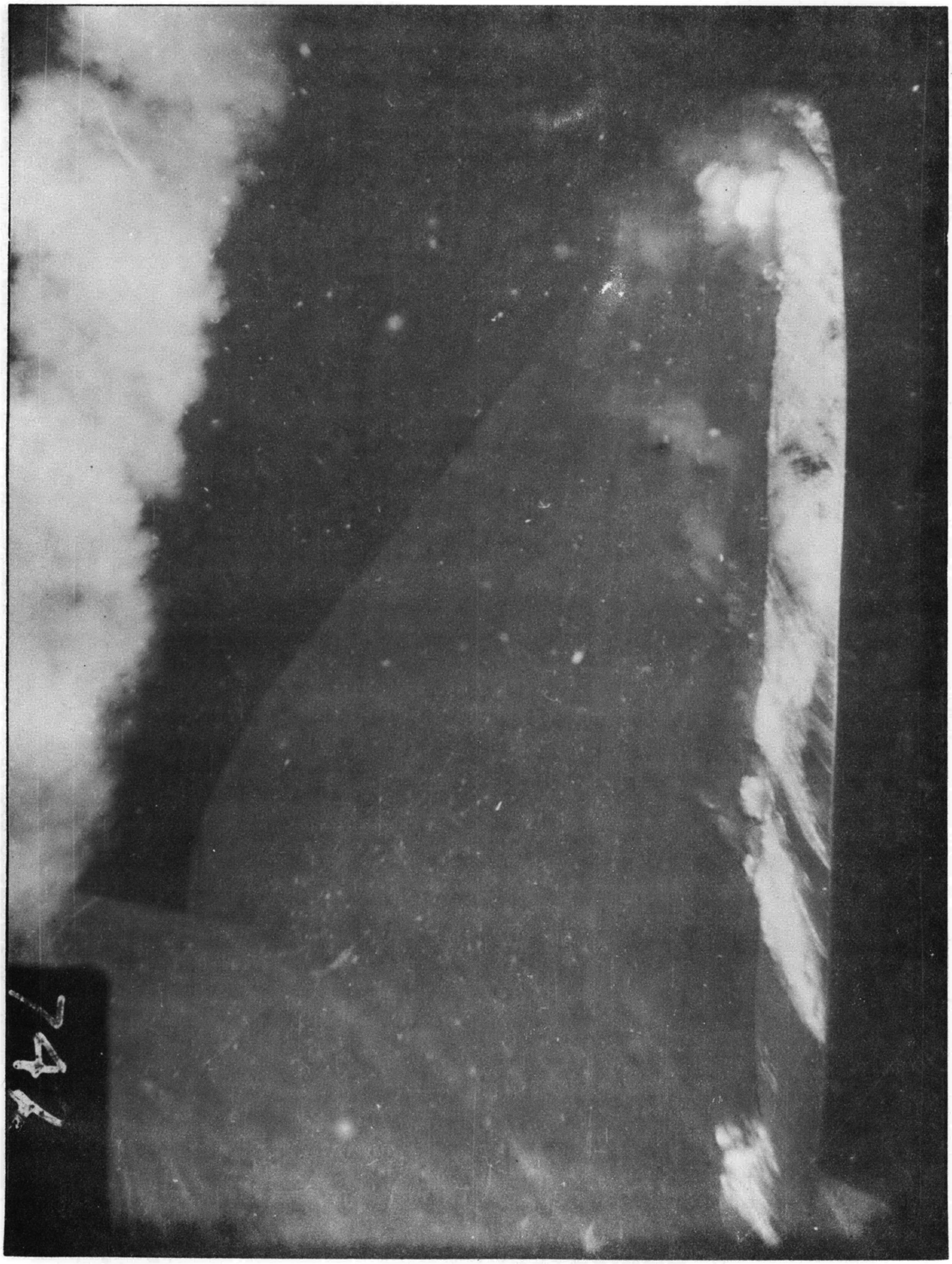

FIG 5. FACE CAVITATION ON FULL SCALE PROPELLER

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$$\text{AT } \frac{V}{V_{\text{CR. MODEL}}} \simeq 1.88$$

FIG 6. MODEL FACE CAVITATION AT $\frac{V}{V_{CR.\ MODEL}} = 1.88$

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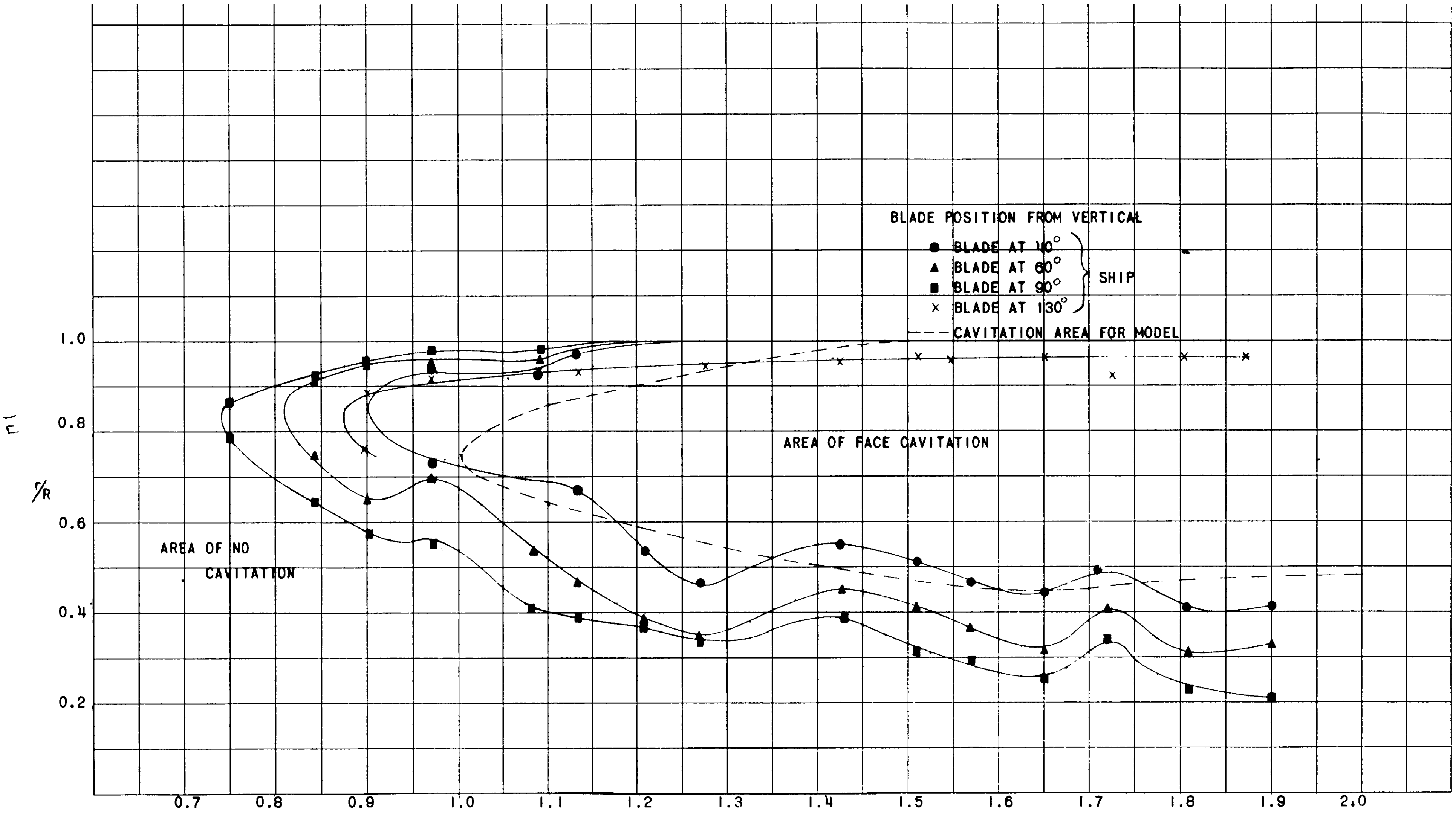

FIG 7. VARIATION OF FACE CAVITATION

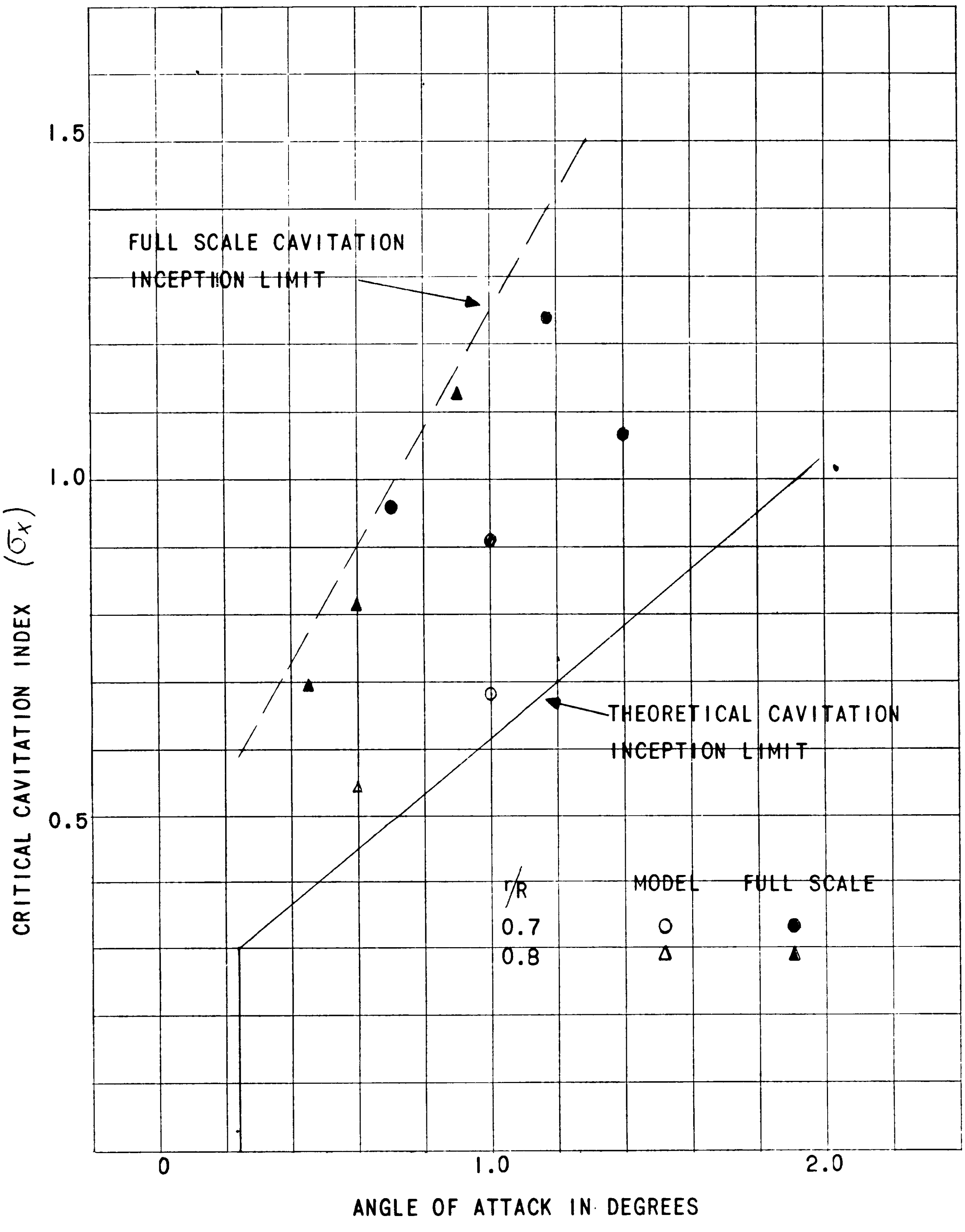

FIG 8. VARIATION OF CAVITATION INDEX WITH ANGLE OF ATTACK