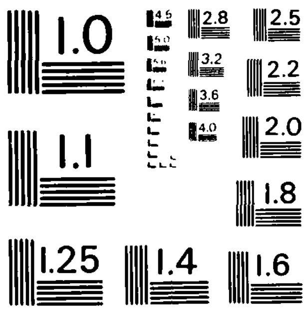
AD-A131 989 PREDICTION OF PARTIAL CAVITATION ON MARINE PROPELLERS 1/1
(U) HYDRONAUTICS INC LAUREL MD P N MAJUMDAR SEP 82
TR-7823-2 N00014-78-C-0144

UNCLASSIFIED F/G 20/4 NL

END
DATE
FILMED
9-83
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AD A131989

PREDICTION OF PARTIAL CAVITATION
ON MARINE PROPELLERS

by
P. N. Majumdar

September 1982

Tracor Hydronautics, Inc.

7210 Pindell School Road ... Maryland 20707

83 08 30 171

HYDRONAUTICS, Incorporated

TECHNICAL REPORT
NO. 7823-2

PREDICTION OF PARTIAL CAVITATION ON MARINE PROPELLERS

by
P. N. Majumdar

September 1982

Prepared for

David W. Taylor Naval Ship Research and Development Center
Under
U. S. Navy General Hydromechanics Research Program
Office of Naval Research Contract N00014-78-C-0144

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: 7823-2	2. GOVT ACCESSION NO.: AD-A131989	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): Prediction of Partial Cavitation on Marine Propellers		5. TYPE OF REPORT & PERIOD COVERED: Final, 4/1978 - 6/1982
		6. PERFORMING ORG. REPORT NUMBER: 7823-2
7. AUTHOR(s): P. N. Majumdar		8. CONTRACT OR GRANT NUMBER(s): N00014-78-C-0144
9. PERFORMING ORGANIZATION NAME AND ADDRESS: HYDRONAUTICS, Incorporated		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS: Office of Naval Research Washington, D.C.		12. REPORT DATE: September 1982
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): David W. Taylor Naval Research and Development Center Bethesda, Maryland		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release - Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Marine propellers
Cavitation
Partial Cavitation
Unsteady inflow

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The application of a theoretical method for predicting unsteady leading edge cavitation on two-dimensional foil sections with finite leading edge radii to the prediction of unsteady partial blade cavitation on marine propellers is discussed. The method is used, together with the unsteady propeller lifting surface theory developed by Kerwin at MIT to predict partial leading cavitation on a propeller for which extensive model test data are available. It is concluded that the method generally

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) predicts the occurrence and transient behavior of the blade cavities well.

TABLE OF CONTENTS

LIST OF FIGURES

NOTATION

C_L	Lift coefficient
P_∞	Free stream pressure
r	Local blade radius
R	Propeller radius
t	Time
V	Velocity
V_c	Circumferential velocity
V_T	Tangential velocity component of wake
V_A	Axial velocity component of wake
V_∞	Free stream velocity
δ	Propeller shaft inclination angle
θ	Blade angular position
σ	Cavitation number
ω	Frequency or rotation
Ω	Blade rate of rotation

1.0 INTRODUCTION

This report describes work carried out by HYDRONAUTICS, Incorporated as part of a study of partial chord-length cavities under Office of Naval Research Contract N00014-78-C-0144. This work is sponsored under the U.S. Navy General Hydromechanics Research (GHR) program administered by the David W. Taylor Naval Ship Research and Development Center (DTNSRDC).

The total period of this contract has been four years, beginning in April 1978 and ending in May 1982. During the first two years of this contract a theory was developed at HYDRONAUTICS giving a mathematical representation of the phenomenon of inception of leading-edge cavity as well as its extent on hydrofoils and wings in uniform flow. During this period numerical methods were developed, based on this theory, for the computation of leading-edge cavity on an airfoil of given section geometry operating in uniform flow at zero on finite angle of attack. Computational results showed very good agreement with experiment. References 1 and 5 give the details of theory development and the correlation of the numerical results with experimental data.

During the third year the HYDRONAUTICS cavity flow theory was extended to permit its use for the prediction of inception and fluctuation of leading-edge cavity on a marine propeller blade. Using the theory in this extended form, a numerical prediction was made of the inception and fluctuation of leading-edge cavity on a three-dimensional marine propeller blade undergoing a purely sinusoidal fluctuation of angle of attack, such as occurs with operation of a marine propeller with an inclined shaft, and uniform inflow.

In addition, during the third year, the cavity-flow theory was also extended to make it applicable to noncavitating flows involving wakes and separation bubbles. A paper describing this work was presented in October 1980 at the Thriteenth Symposium on Naval Hydrodynamics in Tokyo, Japan. Details of the numerical example for the inclined-shaft marine propeller and a copy of this Symposium paper were included in Reference 6.

During the final year of this contract, a validation study for a numerical method for predicting unsteady, partial chord blade cavities on marine propellers, which is described in detail in this report, and is based on the HYDRONAUTICS cavity flow theory, was conducted for typical marine propeller operating in a realistic, non-uniform ship wake. Numerical predictions were made for the inception and fluctuation of blade leading edge cavities on a propeller operating in the wake of a typical single-screw cargo ship. The predicted results were then compared with the experimental observation of model of the propeller under the same operating condition.

As described in Section 4.0 of this report, it was originally planned to consider at least one additional propeller in the validation study. However, there was not found another set of data clearly defining suitable leading edge cavitation over a significant percent of blade length and at an adequate number of angular positions of the blade. An inclined-shaft, uniform-flow propeller cavitation test was then conducted in the HYDRONAUTICS high-speed, free-surface wave channel with a container ship propeller model. Unfortunately suitable leading edge cavities were not obtained in this test.

The present report contains the results of numerical prediction of leading-edge cavity made for the inclined-shaft propeller operating in uniform flow (as presented in Reference 6) and the results of the validation study made for the cargo ship propeller.

2.0 NUMERICAL PREDICTION OF MARINE PROPELLER CAVITATION

Numerical predictions were made of the inception and fluctuation of leading-edge cavities at three representative radial blade sections of the selected propellers. Propeller lifting-surface theory was used, in conjunction with Lighthill's Rule (Reference 1) for flow at foil leading edges, to predict the distributions of perturbation velocities and pressure distribution due to blade thickness and loading for each of the selected blade sections. Calculations were carried out at 24 angular positions of the propeller blade, using even, 15-degree increments. The resulting velocity distributions were then used in conjunction with the blade section leading-edge cavity-flow theory developed at HYDRONAUTICS (References 1 and 5), to compute unsteady propeller blade cavity lengths.

2.1 Description of Computational Procedure

For each selected blade section and each of the twenty-four angular positions of the blade, the perturbation velocities due to circulation and blade thickness were obtained using computer program PUF-2, Reference 3. This program is based on lifting-surface theory and was developed at MIT for the computation of unsteady thrust and tongue of a propeller operating in non-uniform flow. For each selected blade section, program PUF-2 gave the perturbation velocities at nine chordwise locations. A continuous chordwise distribution of these velocities was obtained from the nine discreet values by means of a cubic spline fit.

Of the nine points obtained from the results provided by PUF-2, the point nearest to the leading edge was 2.5 percent of chordlength from the leading edge. A distribution of the perturbation velocities was needed between the leading edge and this point. This distribution was obtained using Lighthill's Rule, Reference 1. In order to use Lighthill's Rule an estimate of the blade section angle of attack was needed at each angular position of the blade. This estimate was made in the manner described below for each blade section of interest.

Section lift coefficients were calculated using a computer program based on the lifting-line theory for desired value of blade section and blade angular position. Using the known physical camber of each blade section and the lifting-surface for camber presented in Reference 4, the effective lift coefficient due to camber was estimated. The section lift coefficient due to angle of attack was then obtained by subtracting this lift coefficient due to camber from the total section lift coefficient determined using lifting-line theory. The angle of attack for the equivalent 2-D airfoil section was then obtained by dividing the lift coefficient due to angle of attack by the section lift-curve slope.

After the perturbation velocities were obtained for each blade section and blade angular positions, computer programs based on the HYDRONAUTICS cavity-flow theory, as described in References 1 and 5, were used to predict the section leading edge cavity geometry at each section and angular position. For each blade section, an initial estimate of cavity volume growth (or collapse) rate was made by the quasi-steady treatment of calculating the cavity volumes at the twenty-four angular positions and obtaining the local rates at these positions by using the calculated lengths. These growth (or collapse) rates of cavity-volume were then incorporated into the computations and the cavity volumes were recalculated at the twenty-four angular positions. The new rates were then calculated. This procedure was repeated until the local rate of growth (or collapse) at each blade position converged within a specified tolerance. Corrected cavity growth (or collapse) rates due to fluctuation of angle of attack were thus obtained at the selected blade sections.

The unsteady cavity flow predictional methods which have been developed as part of this contract, are two-dimensional methods. It has been previously demonstrated that the methods can be successfully applied to finite aspect ratio foils. It was hypothesized, based on this experience with three-dimensional hydrofoils, that the methods should be applicable to marine propeller blades in which the cavity spanwise extent was significantly greater than cavity chordwise extent or length and in which this cavity length did not change too rapidly with radius. The method is only applicable to leading edge cavities which are distinct from tip vortex cavities. Validation of the applicability of these cavity flow methods to the prediction of unsteady propeller cavitation therefore requires test data for a propeller with leading edge cavities of this type.

3.0 PREDICTION OF CAVITATION ON MARINE PROPELLER ON INCLINED SHAFT

Numerical predictions were made of inception and time variation of leading-edge cavitation on a propeller in which the blades were undergoing a purely sinusoidal fluctuation of angle of attack. This was done by considering a marine propeller operating on an inclined shaft in uniform flow. The computations were carried out for two representative blade sections, 0.684R and 0.937R, where R is the overall radius of the propeller. Using the methods described in Section 2, the fluctuating cavity lengths and volumes were obtained at these two blade sections.

3.1 Selection of Propeller

A typical single-screw cargo ship propeller was chosen for this study. This was one of the two propellers designed by DTNSRDC, for which model tests had been conducted at MIT in a realistic axial-flow ship wake in order to study their cavitation characteristics. This propeller was chosen because it was also planned to use the MIT test data to validate the HYDRONAUTICS cavity-flow theory for the case with a typical axial wake. This latter effort could not be carried out, because these data could not be obtained from MIT (See Section 4.1). The principal particulars of this propeller model are given below:

Overall Radius, R	:	6 inches
Design RPM, N	:	1500
Rotational Speed, N	:	1500 rpm
No. of Blades	:	5
Pitch-Diameter Ratio at 0.7 R	:	1.077
Expanded Area Ratio	:	0.725
Blade Section Type	:	NACA 66
Blade Camber Type	:	a = 0.8 meanline

3.2 Description of Inflow

The orientation of propeller with respect to inflow is illustrated in Figure 1. The flow conditions used in computations are given below:

Freestream Flow Velocity, U_∞	:	12.33 knots
Inclination of Flow to Propeller Axis, δ	:	10 degrees
Freestream pressure, p_∞	:	11.8 psi
Mean Cavitation Number at 0.684R	:	0.67
Mean Cavitation Number at 0.937R	:	0.39

As shown in Figure 1, the axial component of the free-stream velocity, V_A, is constant over the propeller disk and is:

$$V_A = U_\infty \cos \delta \ .$$

The shaft inclination produces a tangential or circumferential velocity component which has a mean value of Ωr, where Ω is the constant rotational speed of the propeller and r the radial distance of the blade section from the axis of rotation. This tangential velocity also has a time-varying component,

$$V_T \sin \omega t,$$

which is independent of the radial location of the blade section. This fluctuating part of the tangential velocity is due to the propeller axis inclination to the flow. The amplitude and phase ofthis fluctating velocity component are

$$V_T = U_\infty \sin \delta$$

and

$$\omega t = \theta, \text{ respectively,}$$

where θ is the blade angular position as defined in Figure 1.

The magnitude of the resultant inflow velocity at a blade section at radius r is then

$$V_R = \sqrt{{V_A}^2 + {V_c}^2}$$

where

$$V_A = U_\infty \cos \delta$$

and

$$V_c = \Omega r + V_T \sin \omega t$$

$$= \Omega r + U_\infty \sin\delta \sin\theta$$

3.3 Calculated Results

The predicted results are given in Figures 2 through 6. Figure 2 shows the circumferential fluctuation of lift coefficient at radii 0.684R and 0.937R. This variation is due to the propeller axis inclination to the uniform flow, resulting in sinusoidal variation of blade section geometric angle of attack. The resulting cavity length variations at the two blade sections are shown in Figures 3 and 4. Figure 5 gives the angular rate of variation of cavity volume and Figure 6 gives the fluctuation of cavity volume with respect to the mean volume.

3.4 Discussion of Results

As seen in Figures 3 and 4, the propeller blade had cavitation at the two radii of interest at all angular positions of the blade. The inception (onset) and washoff of cavitation due to varying angle of attack therefore were not seen at any blade position, because the blade section angle of attack was large enough at all positions of the blade to produce leading edge cavitation. As seen in Figure 6, the fluctuation of cavity volume or cross-sectional area is small and does not exceed 27 percent of the mean volume at 0.684R or 30 percent of the mean volume at 0.937R.

4.0 VALIDATION STUDY FOR PROPELLER IN NONUNIFORM FLOW

4.1 Selection of Propeller and Inflow

The selection of a suitable propeller and inflow for use in validating the predictional methods developed under this contract was largely based on the availability of a set of experimental data which gave a clear definition of cavitation on propeller blade at various angular positions of the blade while operating in a well defined wake.

At the time this validation study was proposed, it was intended that the study be conducted for two configurations of propeller operation: the propeller operating on an inclined shaft, in a horizontal uniform flow, and hence undergoing a purely sinusoidal variation of angle of attack and the propeller operating in a typical single-screw cargo ship wake, which was dominated by variations in axial velocity.

A search of the available literature was made for cavitation data for the uniform-flow, inclined-shaft propeller operation; but no set of experimental data clearly defining the cavitation on propeller blade at a number of angular positions of the blade was found. An inclined-shaft, uniform-flow propeller cavitation test was then conducted in the HYDRONAUTICS high-speed, free-surface water channel with a container ship propeller model of HYDRONAUTICS design. Unfortunately, no suitable data were obtained from these model test. The model test was conducted for a shaft inclination of 7.5 degrees and for various combinations of free-stream velocity, rpm and static pressure. Clear, partial leading-edge cavitation could not be obtained at any test condition. Cavitation, when it occurred, remained mainly in the tip region, distorted by tip-vortex cavitation, and the cavity in that region extended over the whole chordlength.

For validation for a propeller operating in a typical single screw ship wake, it was originally proposed to use data from recent cavitation tests conducted at MIT, for the Maritime Administration, with a typical single-screw cargo ship propeller. Unfortunately, MIT was unable to make available suitable test data for this study. After a search of the published test data, those presented in Reference 2 were selected for this study. These data are from a propeller cavitation test performed at the Norwegian Ship Model Experiment Tank in the wake of a typical single-screw cargo ship. Details of the propeller geometry were supplied by Dr. Erling Huse, author of Reference 2.

4.2 Description of Selected Propeller

The propeller model designated as P-548 by the Norwegian Ship Model Experiment Tank was selected for this study. The principal particulars of this propeller model are given below:

Overall Radius, R	:	3.78 inches
rpm, N	:	1140
Rotational Speed,	:	1140 rpm
No. of Blades	:	4
Pitch-Diameter Ratio at 0.7R	:	1.077
Expanded Area Ratio	:	0.738
Blade Section Type	:	B-Series (Wageningen)
Blade Camber Type	:	a = 0.8 meanline.

Some geometric properties of the propeller blade geometry are given in Figure 7. Details of propeller geometry are not presented at the request of Dr. Huse.

4.3 Description of Ship Wake and Its Effect on Cavitation

A velocity contour map of ship wake including the location of the propeller is given in Figure 8. This wake is represented by contours of constant axial inflow velocity made dimensionless with respect to U_∞, the freestream velocity. The inflow to the propeller in this wake is assumed to be purely axial, i.e., the flow velocity vector is parallel to the axis of rotation of the propeller.

The physical properties of the propeller inflow in the model experiment set-up were as follows:

Freestream Velocity, U_∞	:	14.11 ft/s
Freestream Pressure, p_∞	:	13.35 psi
Mean Cavitation Number at 0.684R	:	0.53
Mean Cavitation Number at 0.811R	:	0.39
Mean Cavitation Number at 0.937R	:	0.30

4.4 Calculated and Experimental Results

Results from numerical prediction and experiment are given in Figures 9 through 14. Figure 9 shows the circumferential variation of blade section lift coefficient at the three radii of interest. Figure 10 gives the fluctuation of cavity volume, with respect to the maximum volume, at each of these radii. Figures 11, 12, and 13 show the circumferential variation of cavity-length, as obtained from both the numerical prediction and the model test, at 0.684R, 0.811R and 0.937R respectively.

As described in Section 2.1, the three-dimensional propeller blade problem was reduced to one in two dimensions, where the calculations of the equivalent 2-D section angle of attack required the two-dimensional lift-curve slope. For the numerical results presented in Figures 11-13, the 2-D lift-curve slope used was that given by inviscid theory, viz., 2π. However, experimental data indicate that it is more appropriate to use a value of about 5.73 (0.1 per degree) for the lift curve slope of typical propeller blade sections. A comparison was made, for the blade section at 0.684R, between predictions of cavity made using these two lift-curve slopes. Figure 14 shows this comparison. As seen in this figure, the predicted leading-edge cavity changed only slightly with this change in the value of lift-curve slope, and the difference is not considered significant.

Figure 15 shows the variation of cavity length with axial velocity, for the first quadrant of propeller blade rotation.

4.5 Discussion of Results

The purpose of that phase of the contract discussed here was validation of the applicability of HYDRONAUTICS cavity-flow theory, to the prediction of unsteady marine propeller blade leading edge cavitation. The procedure used for propeller cavitation prediction, as described in Section 2.1, involved five steps, each of which significantly influences the prediction of cavitation. These steps are:

(a) computation of blade surface perturbation velocities using a slightly modified version of lifting surface computer program PUF-2;

(b) computation of blade section lift coefficient at each angular position of blade using a lifting-line computer program;

(c) use of tabulated lifting-surface data to calculate the lift coefficient due to camber for an equivalent 2-D airfoil section;

(d) use of a 2-D lift-curve slope to obtain the section angle of attack;

(e) use of the HYDRONAUTICS cavity-flow theory for computation of unsteady cavity length and volume.

As seen in Figures 11, 12, and 13, the theory agrees quite well with experiment as far as the extent of cavitation. There exist, however, some discrepancies in the point of inception of cavitation and phase of maximum cavitation:

(a) Near the 300° position of the blade, the theory predicts inception of cavitation significantly earlier than is observed in experiment.

(b) In the vicinity of the 180° position of the blade, the theory predicts cavitation while the experiment shows no evidence of cavitation.

(c) The experimental observations lag, in phase, the predicted occurrences of maximum cavitation. This phase lag is especially noticeable at 0.684R and 0.811R radii, where the experiments show maximum cavitation at 15° and about 40° blade-positions, respectively, while the theory predicts maximum cavitation at 0° for all radii.

There are three possible major sources of the disagreements described above. These are: factors influencing the experimental results; computational methods used in program PUF-2 to account for the unsteady effects on the blade loads and surface perturbation velocities; and the cavity-flow theory and associated computational mehtod used to determine the time-history of cavity growth (or collapse) at a given blade position.

Near the 300° location of the blade, the experiment shows a rather significant delay in the observed inception of cavitation relative to theoretical prediction. However, except at the 0.937R radius, where the cavitation is expected to be significantly influenced by three-dimensional effects, the theoretical and experimental blade-position for cavity washoff are in good agreement.

In cavitation-tunnel tests, a delay in cavitation inception will occur if the air content in the tunnel water is not at least saturated, with some free air bubbles. The experiment of this study was conducted in a closed jet water tunnel, and in such tunnels the air content in water is typically less than the saturated value. Therefore, it is possible that the delay in cavitation inception shown in experiment, compared with the theoretical prediction, is due at least in part to a low air content in the tunnel. A low air content might also explain the absence of cavitation in experiment in the vicinity of the 180° position of the blade, where the theory predicts the occurrence of cavitation.

The second possible source to the observed discrepancies is the method employed in program PUF-2 to account for unsteady effects. Figure 15 shows, for the first quadrant of propeller blade rotation, the variation of predicted cavity length with axial velocity in ship's wake. Figure 15 shows that, as the blade enters regions of increasing axial velocity, the predicted cavity length decreases monotonically from its maximum at the 0-degree location of blade. The computational procedure predicts the occurrence of maximum cavity length at the 0-degree location, where the axial velocity is a minimum. This prediction is consistent with the physical phenomenon in the absence of unsteady effects, in which situation the maximum cavity length would occur at the 0-degree location, the location of the maximum blade section inflow angle of attack. On the other hand, the presence of any significant unsteady effects would cause the blade location for maximum cavity length to shift from the location of minimum axial velocity. This phase difference between minimum axial velocity and maximum cavity length does exist in the experimental results (Figures 11, 12, and 13), suggesting, therefore, the presence of the effects of unsteadiness. Because the prediction shows no such difference in phase, it is possible that the unsteady effects were not adequately taken into account by program PUF-2 in the computation of blade surface pertrubation velocities.

It appears that no validation of program PUF-2 based on experimentally measured forces on a single propeller blade as a function of angular positions in an axial wake has been carried out. A validation study was conducted for PUF-2 by Boswell, et al. (Reference 7), but this was for total forces on the propeller and therefore the conclusions derived in Reference 7 do not apply to this study.

Finally, the method used in computing propeller blade leading-edge cavity characteristics may have contributed to the disagreement, between theory and experiment, in the inception and phase. As described in Section 2.1, the time-history of cavity growth (or collapse) was taken into account in the computation through an iterative procedure for the convergence of time-rate of cavity fluctuation at a given blade position. There is a possibility that the time-dependence of the fluctuation of cavity was not fully accounted for by this procedure.

The possible major sources of the disagreements have been discussed above. There is no means with available data of determining which of these sources is (are) the primary contributor(s) to these disagreements. Therefore a more definitive explanation for these discrepencies based on these results is not presently possible.

4.6 Conclusions and Recommendations

Based on the validation effort described in this section, it can be concluded that:

- The proposed method of analysis for unsteady propeller blade leading edge cavitation appears capable of predicting such cavity flows with generally good accuracy.
- The primary differences between the measured and predicted cavity flow fluctuations are in the positions of cavity onset and washoff, and in the absence of a small region of observed cavitation when the blade is in the vertical downward position ([illegible] = 180°).
- There are a number of possible causes for the observed differences between predicted and measured results, including possible scale effects in the model test results used.
- The method appears to be a useful engineering tool for predicting the inception, extent and volume of unsteady blade leading edge cavities.

In order to further improve confidence in the method, additional validation is needed. In particular, validation based on tests with the propeller inclined to a uniform inflow are desirable, as these eliminate the effect of factors such as flow shear and turbulence which are present with typical nonuniform wakes. A comparison with data from the carefully conducted experiments at MIT would be very useful.

REFERENCES

1. Tulin, M. P. and Hsu, C. C., "The Theory of Leading Edge Cavitation on Lifting Surfaces with Thickness," Technical Paper for Det Norske Veritas Symposium, March 1977.

2. Huse, E., "Pressure Fluctuations on the Hull Induced by Cavitating Propellers", Norwegian Ship Model Experiment Tank Publication III, March 1972.

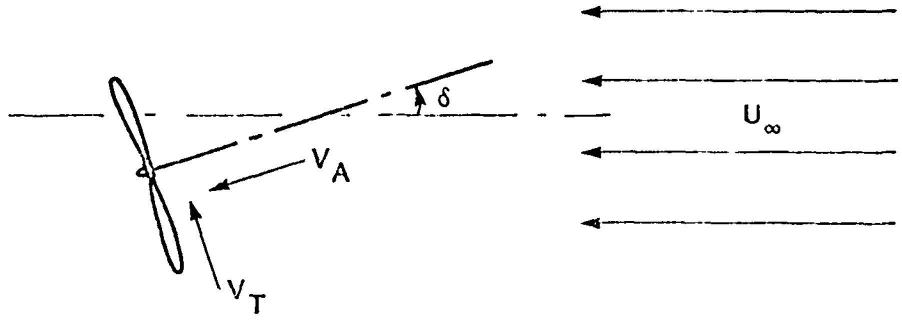
3. Kerwin, J. E., Lee, C-S, "Prediction of Steady and Unsteady Marine Propeller Performance by Lifting-Surface Theory," Transactions SNAME, Vol. 86, 1978.

4. Morgan, Wm. B., Silovic, V., and Denny, S. B., "Propeller Lifting-Surface Corrections," Transactions SNAME, Vol. 76, 1968.

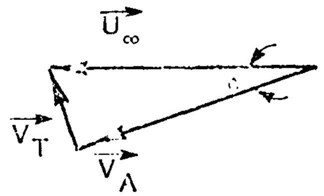
5. HYDRONAUTICS, Incorporated, "A Study of Steady and Unsteady Leading Edge Cavitation on Foils and Wings," GHR Quarterly Progress Report 7823-3, September 1978.

6. Majumdar, P. N., Tulin, M. P., and Hsu, C. C., "Cavity Flow Theory: Its Application to Marine Propellers and Separated Flows," HYDRONAUTICS, Incorporated Progress Report 7823-7, March 1981.

7. Boswell, R. J., Jessup, S. D., and Kim, K-H, "Periodic Blade Loads on Propellers in Tangential and Longitudinal Wakes," Paper 11, SNAME Propellers '81 Symposium, May 1981.



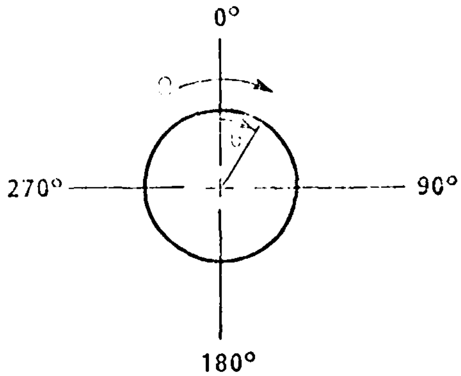
ORIENTATION OF PROPELLER WITH RESPECT TO INFLOW



$$V_A = U_\infty \cos \delta$$

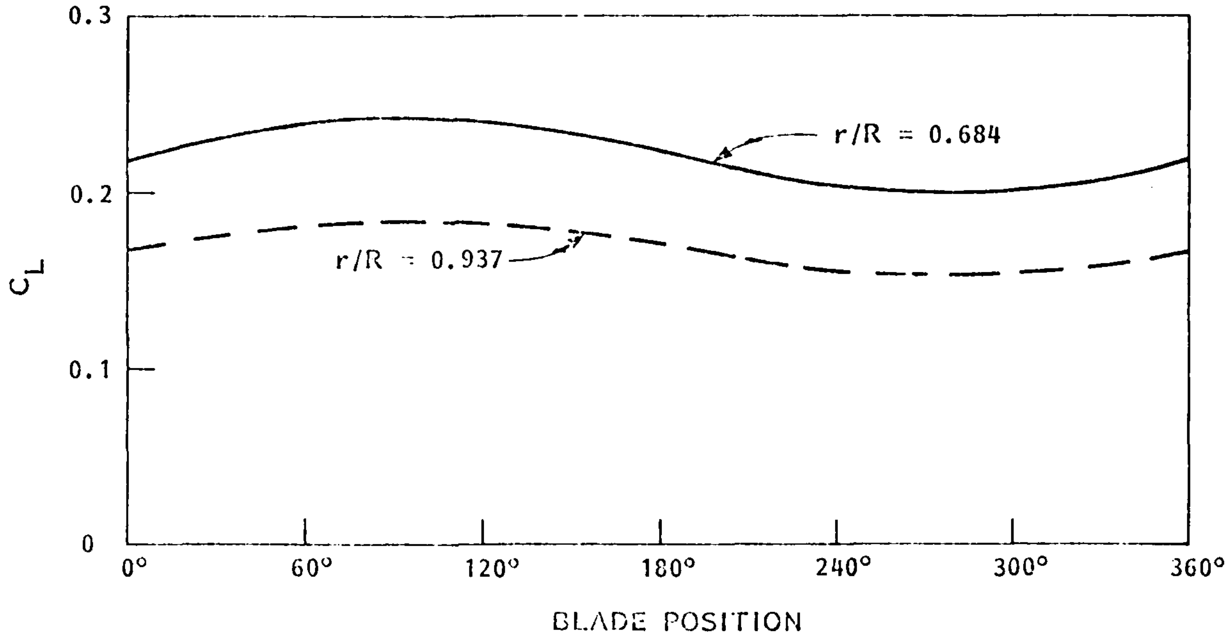
$$V_T = U_\infty \sin \delta$$

RESOLUTION OF INFLOW VELOCITY VECTOR



DIRECTION OF PROPELLER ROTATION
(AS VIEWED LOOKING IN THE DIRECTION OPPOSING AXIAL INFLOW, V_A)

FIGURE 1 - DESCRIPTION OF INFLOW AND PROPELLER OPERATION (INCLINED-SHAFT PROPELLER CAVITATION PREDICTION)



AT r/R = 0.684:

$C_{L_{mean}}$ = 0.2207

EXTREME FLUCTUATIONS ARE

9.75% (+)

AND 9.50% (-)

CORRESPONDING FLUCTUATIONS OF ANGLE OF ATTACK ARE

11.25% (+)

AND 10.90% (-)

AT r/R = 0.937:

$C_{L_{mean}}$ = 0.1689

EXTREME FLUCTUATIONS ARE

9.25% (+)

AND 9.00% (-)

CORRESPONDING FLUCTUATIONS OF ANGLE OF ATTACK ARE

12.50% (+)

AND 12.10% (-)

FIGURE 2 - VARIATION OF LIFT COEFFICIENT (INCLINED-SHAFT PROPELLER CAVITATION PREDICTION)

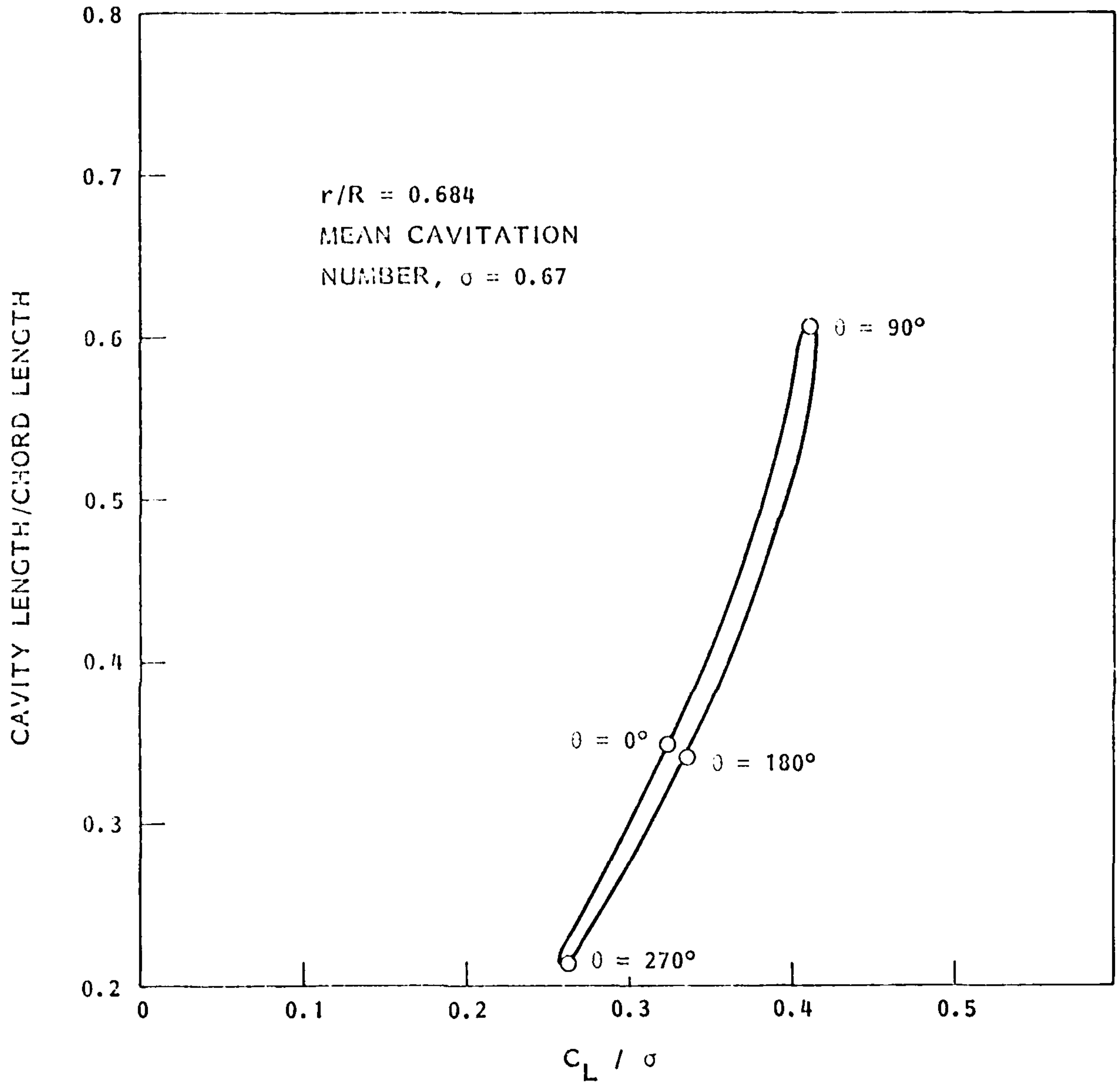


FIGURE 3 - FLUCTUATION OF CAVITY LENGTH AT 0.684R (INCLINED-SHAFT PROPELLER CAVITATION PREDICTION)

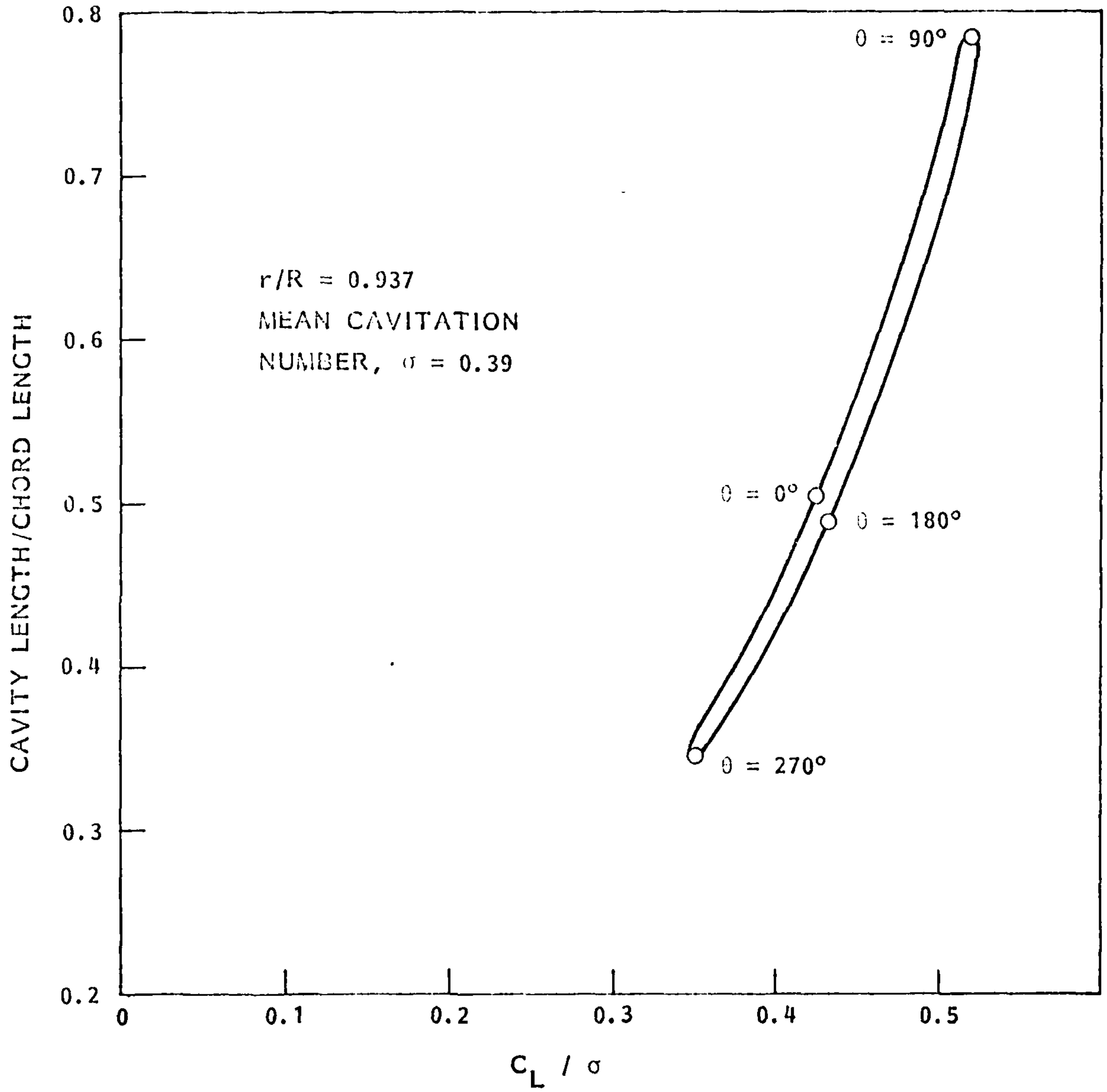


FIGURE 4 - FLUCTUATION OF CAVITY LENGTH AT 0.937R (INCLINED-SHAFT PROPELLER CAVITATION PREDICTION)

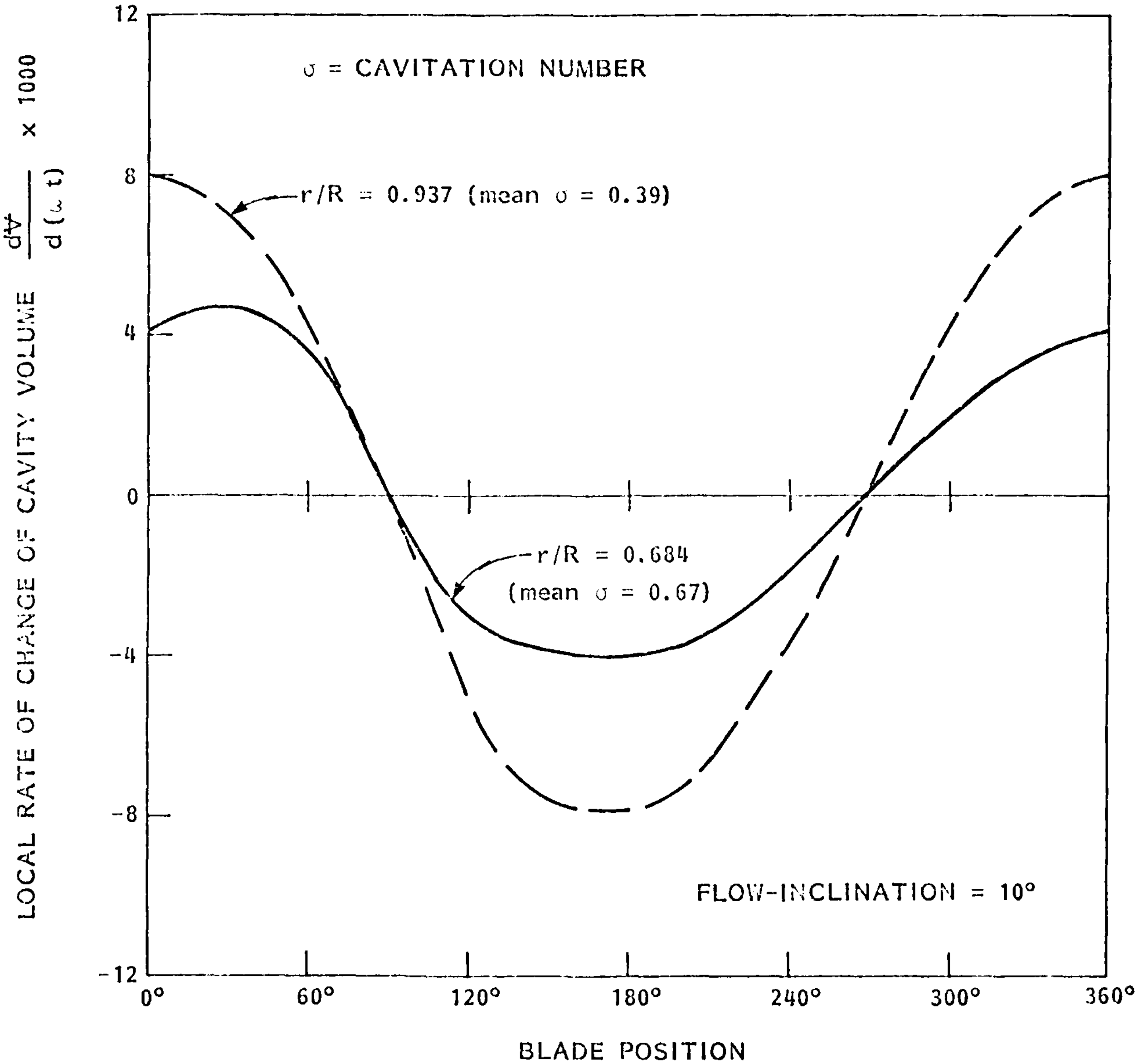


FIGURE 5 - RATE OF CHANGE OF CAVITY VOLUME (INCLINED-SHAFT PROPELLER CAVITATION PREDICTION)

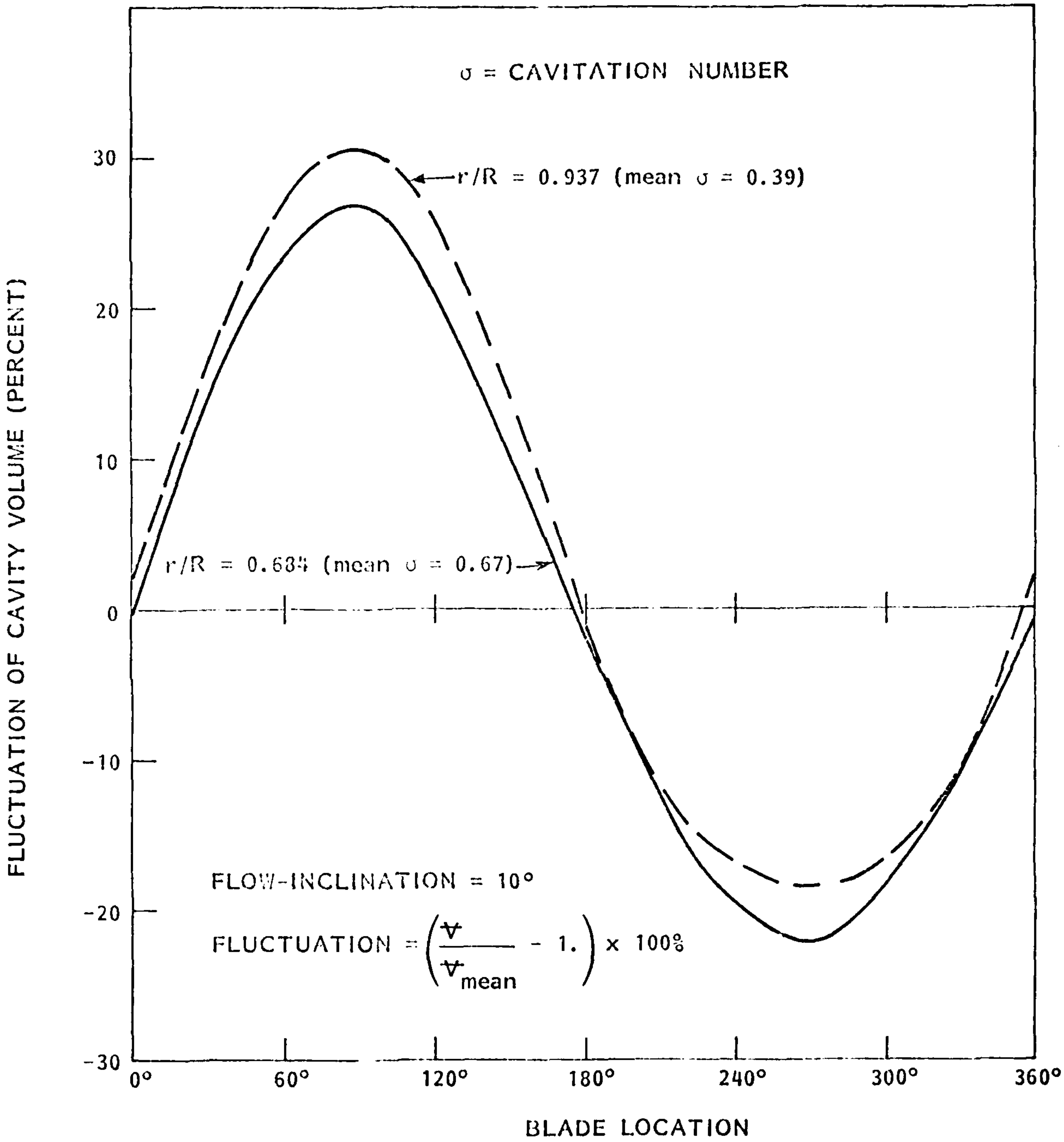
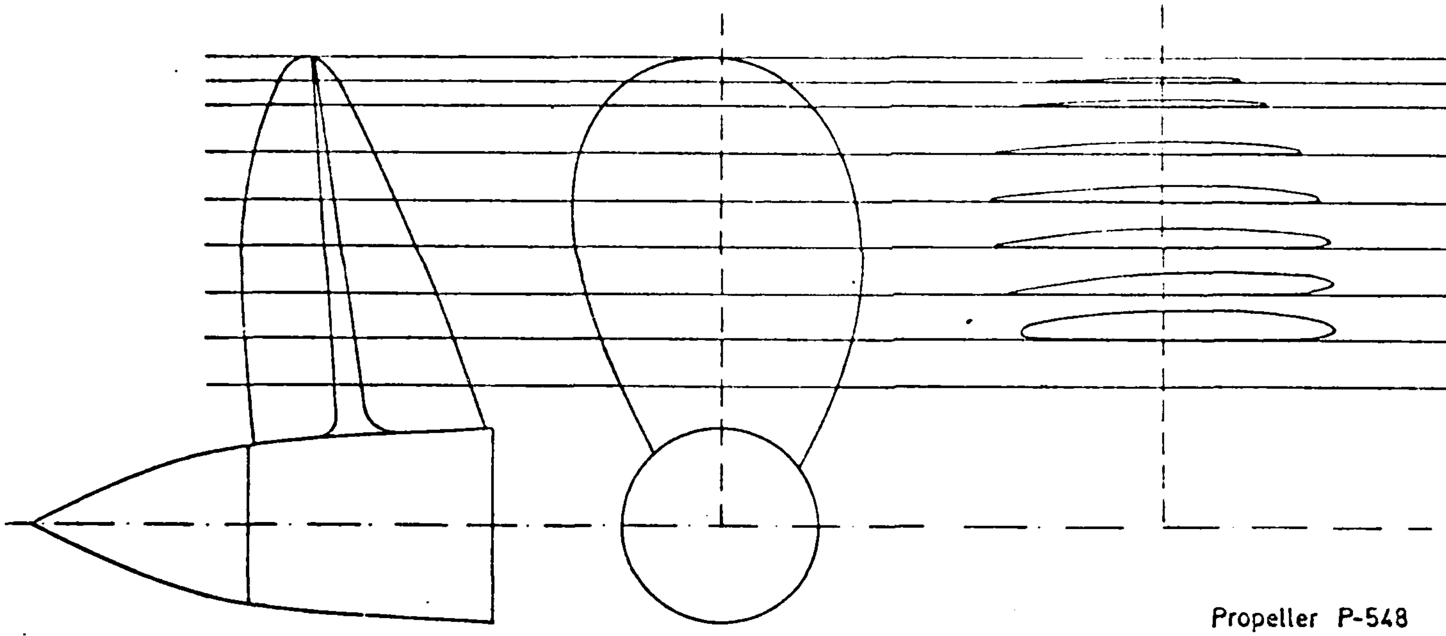


FIGURE 6 - FLUCTUATION OF CAVITY VOLUME (INCLINED-SHAFT PROPELLER CAVITATION PREDICTION)



r/r_t	r [mm]	c_r [mm]	T_{max} [mm]	P [mm]
1.00	96.0	0.0	0.64	186.60
0.95	91.2	39.3	1.08	192.28
0.90	86.4	50.7	1.53	196.92
0.80	76.8	62.5	2.42	203.36
0.70	67.2	67.3	3.30	206.84
0.60	57.6	68.6	4.18	
0.50	48.0	67.3	5.08	208.52
0.40	38.4	64.4	5.96	
0.30	28.8		6.86	202.96

Propeller P-548

Number of blades: 4

Direction of rotation: right-handed

FIGURE 7 - SOME GEOMETRIC DETAILS OF PROPELLER OPERATING IN SHIP WAKE
(TAKEN FROM REFERENCE 2)

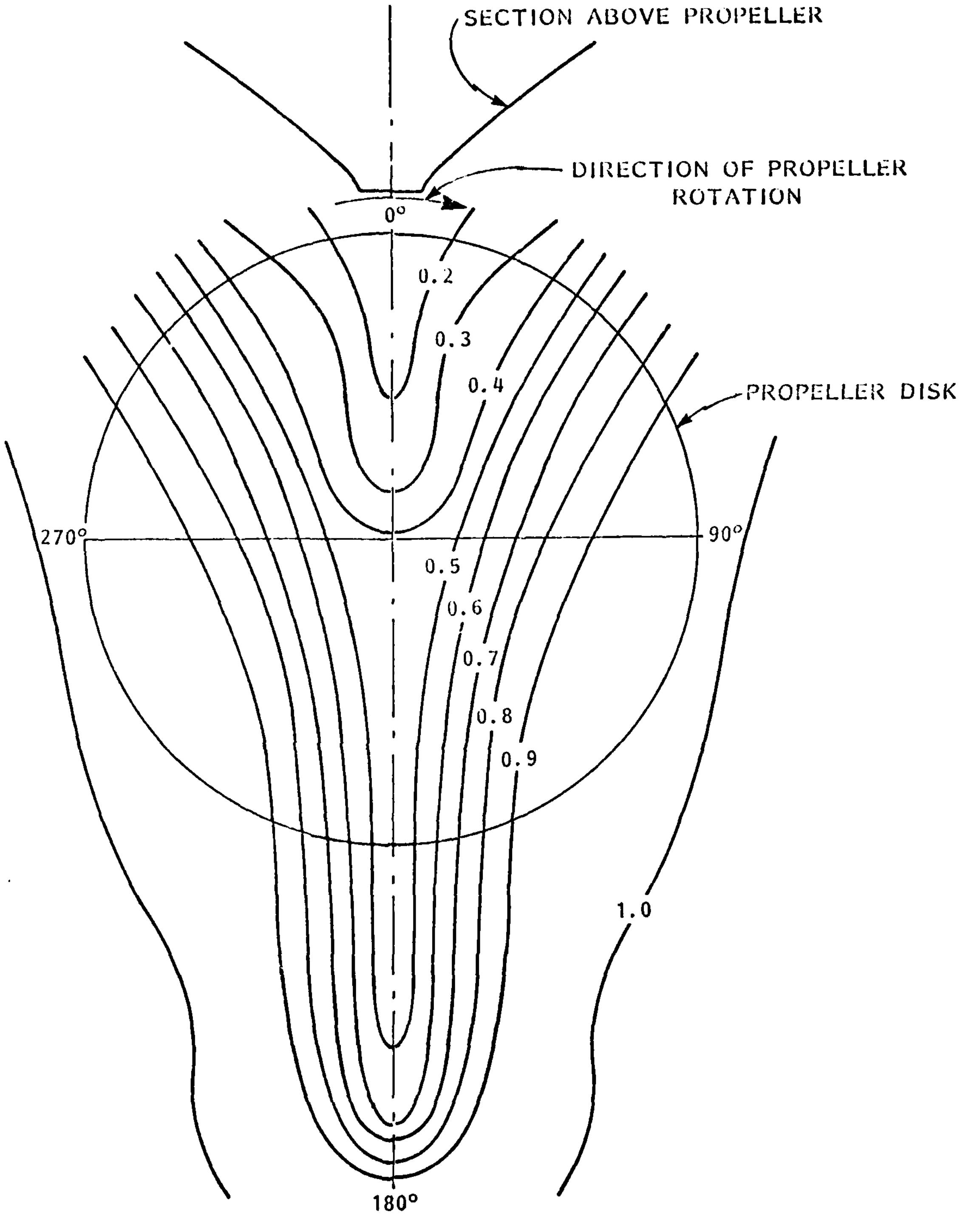


FIGURE 8 - DISTRIBUTION OF VELOCITY IN SHIP WAKE
(TAKEN FROM REFERENCE 2)

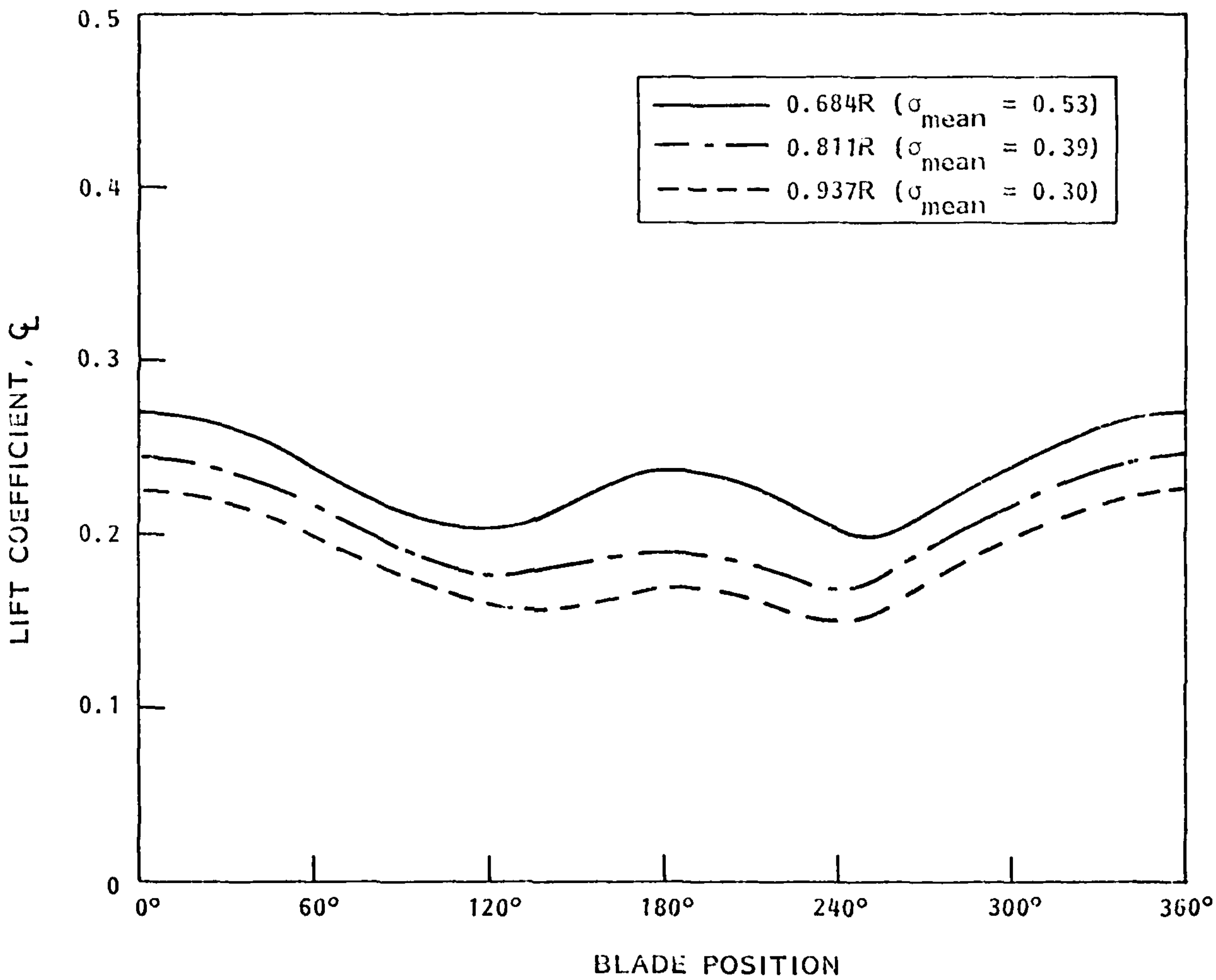


FIGURE 9 - VARIATION OF BLADE SECTION LIFT COEFFICIENT (PROPELLER IN SHIP WAKE)

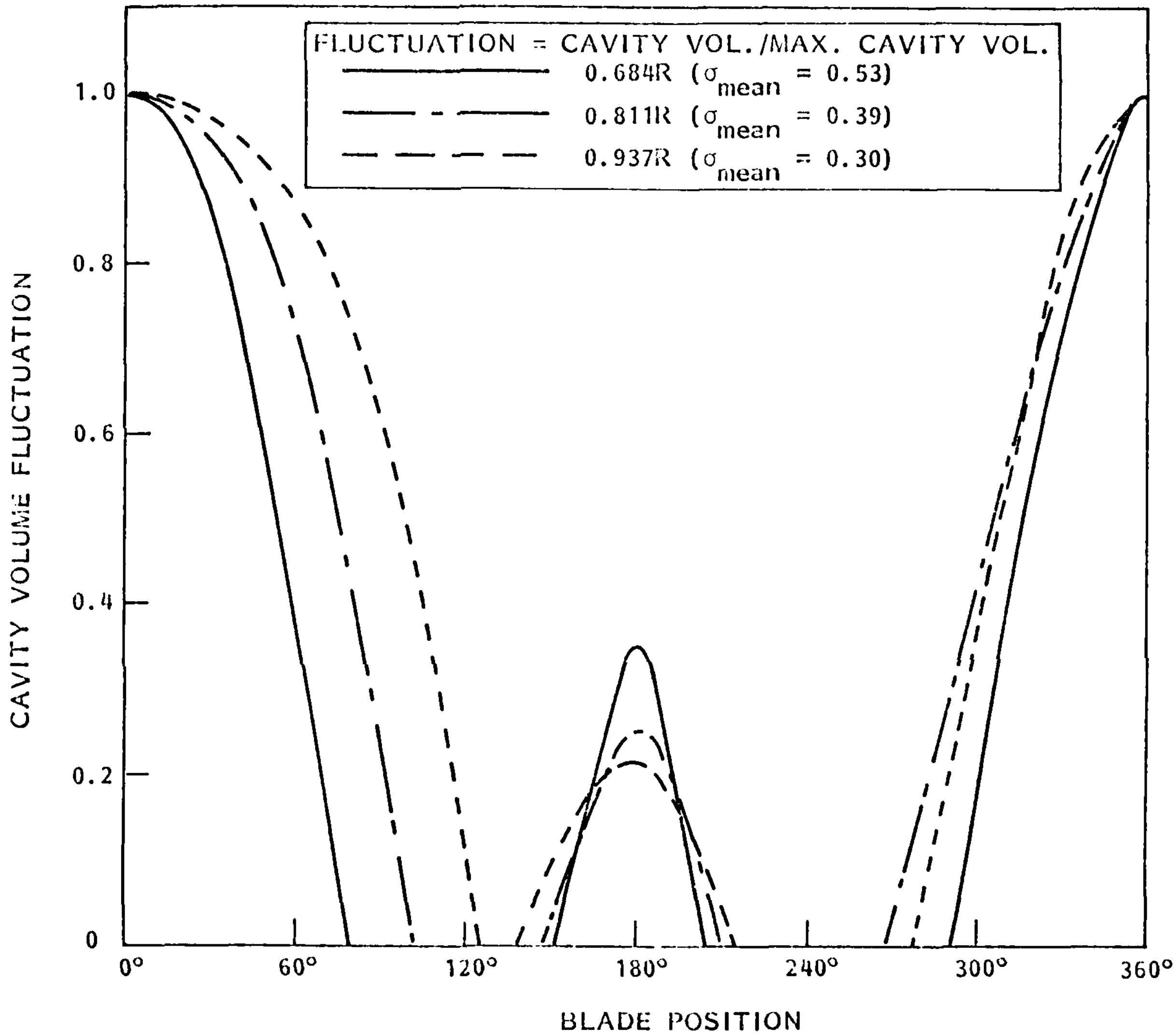


FIGURE 10 - PREDICTED FLUCTUATION OF CAVITY VOLUME (PROPELLER IN SHIP WAKE)

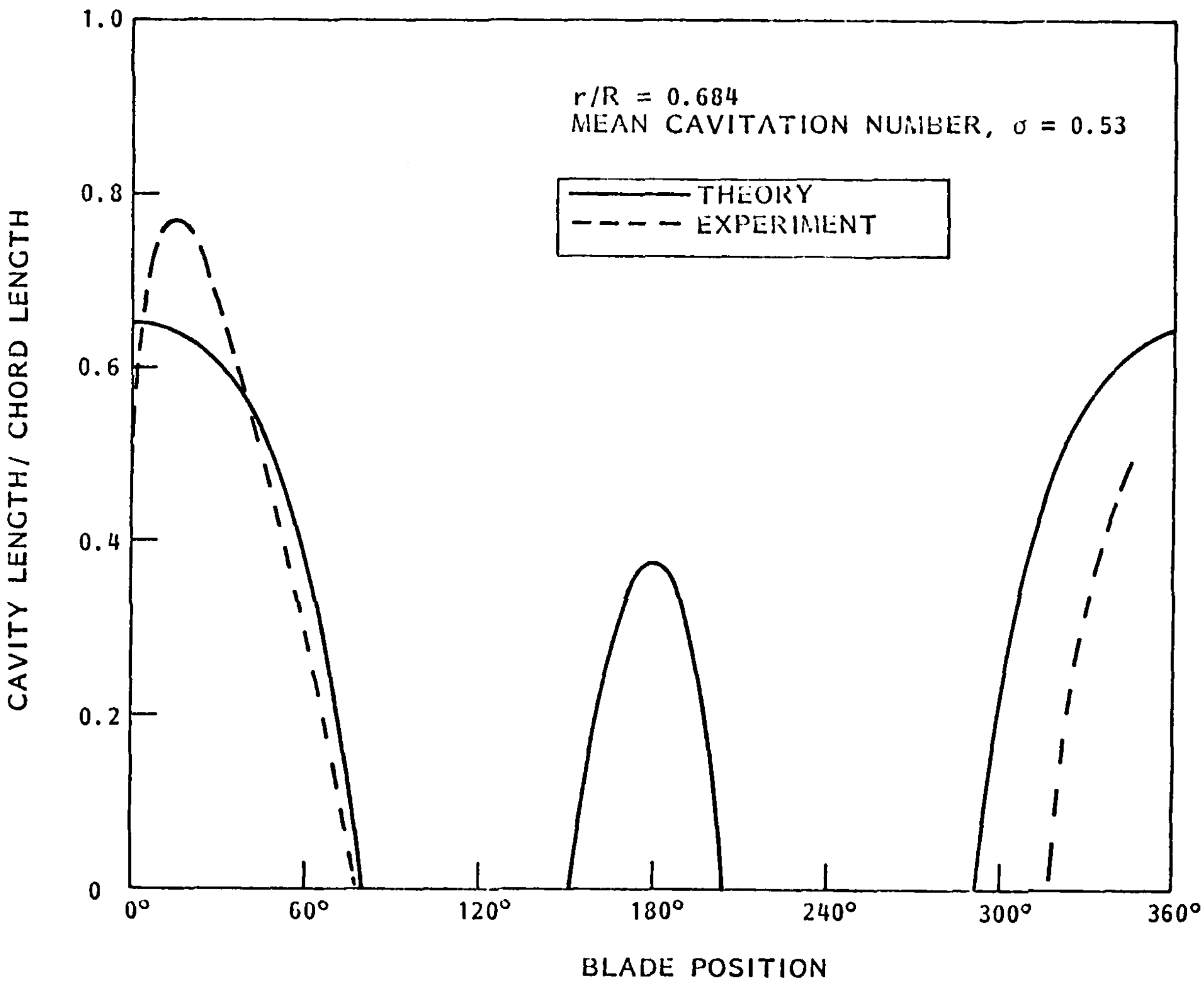


FIGURE 11 - FLUCTUATION OF CAVITY LENGTH AT 0.684 R
(PROPELLER IN SHIP WAKE)

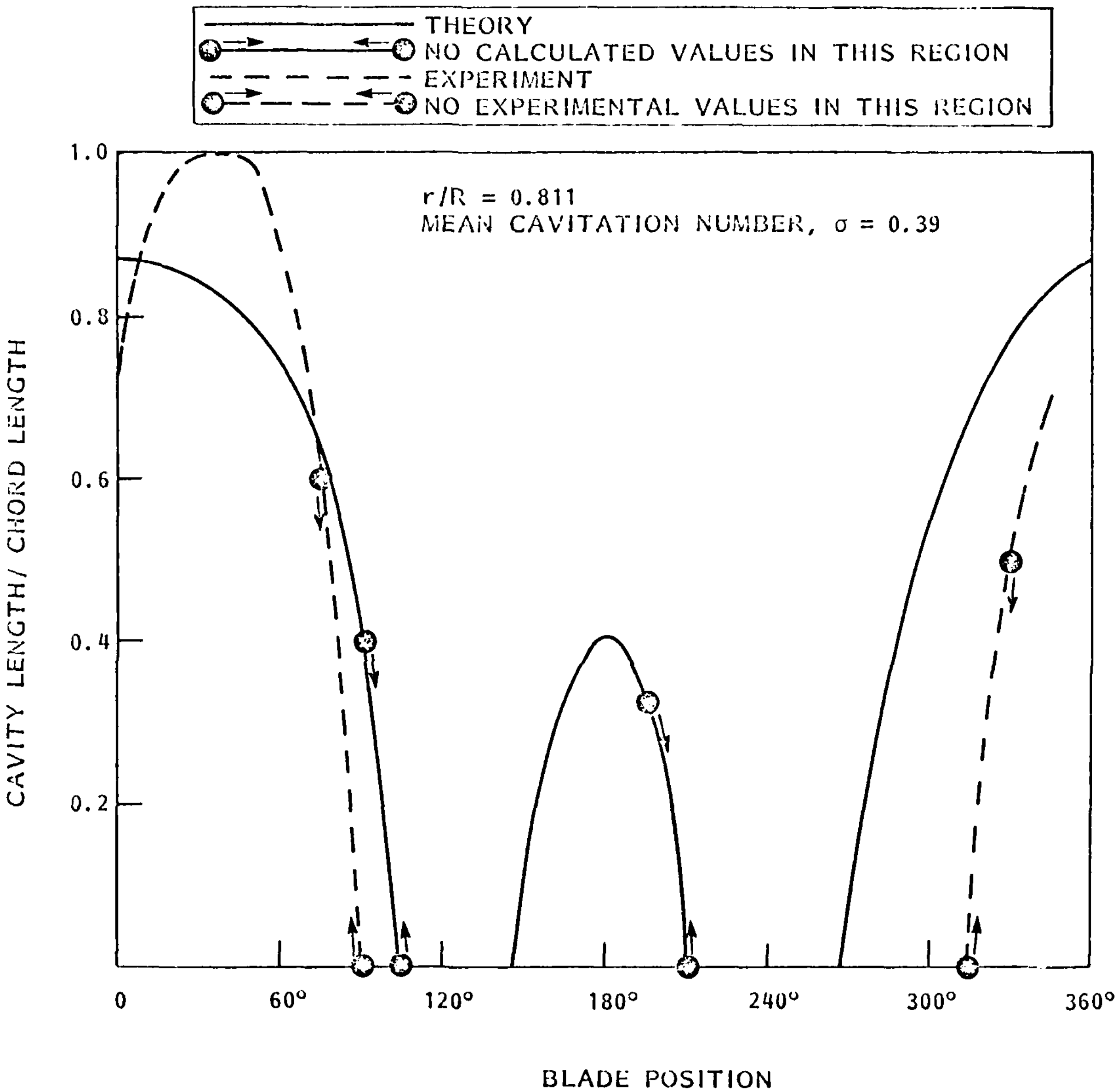


FIGURE 12 - FLUCTUATION OF CAVITY LENGTH AT 0.811R (PROPELLER IN SHIP WAKE)

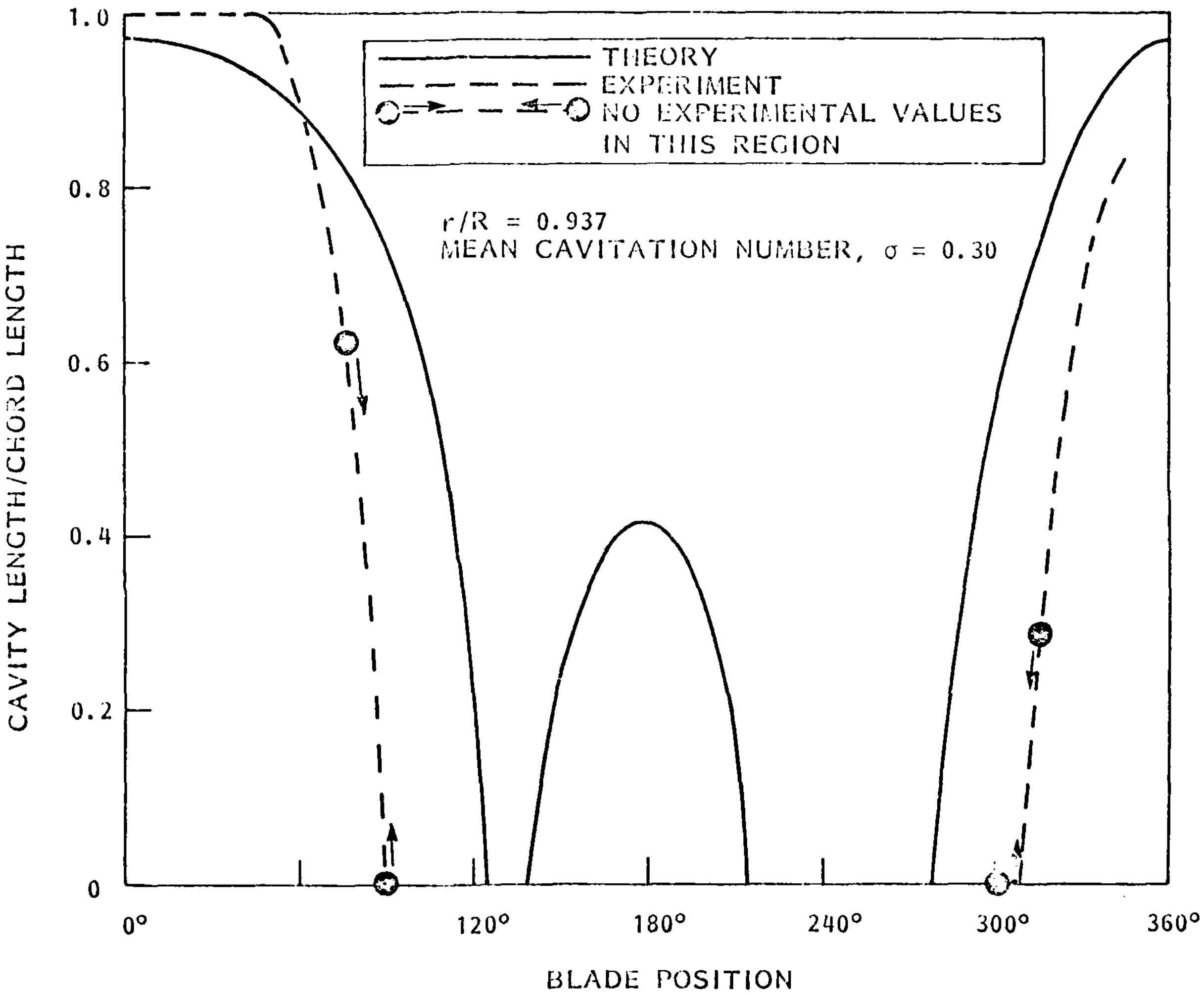


FIGURE 13 - FLUCTUATION OF CAVITY LENGTH AT 0.937 R
(PROPELLER IN SHIP WAKE)

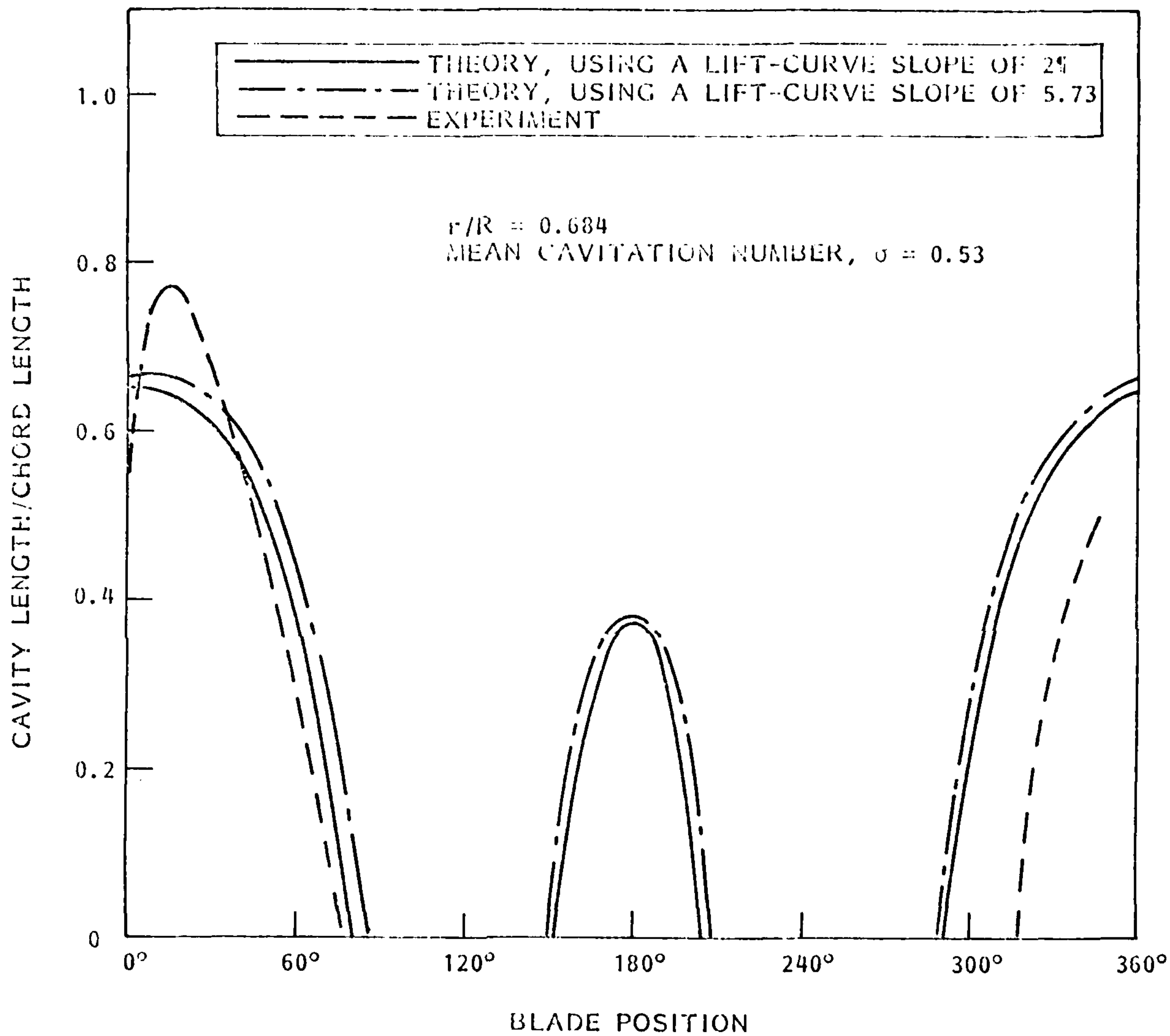


FIGURE 14 - COMPARISON OF PREDICTIONS OF CAVITY AT 0.684R USING TWO VALUES OF LIFT-CURVE SLOPE (PROPELLER IN SHIP WAKE)

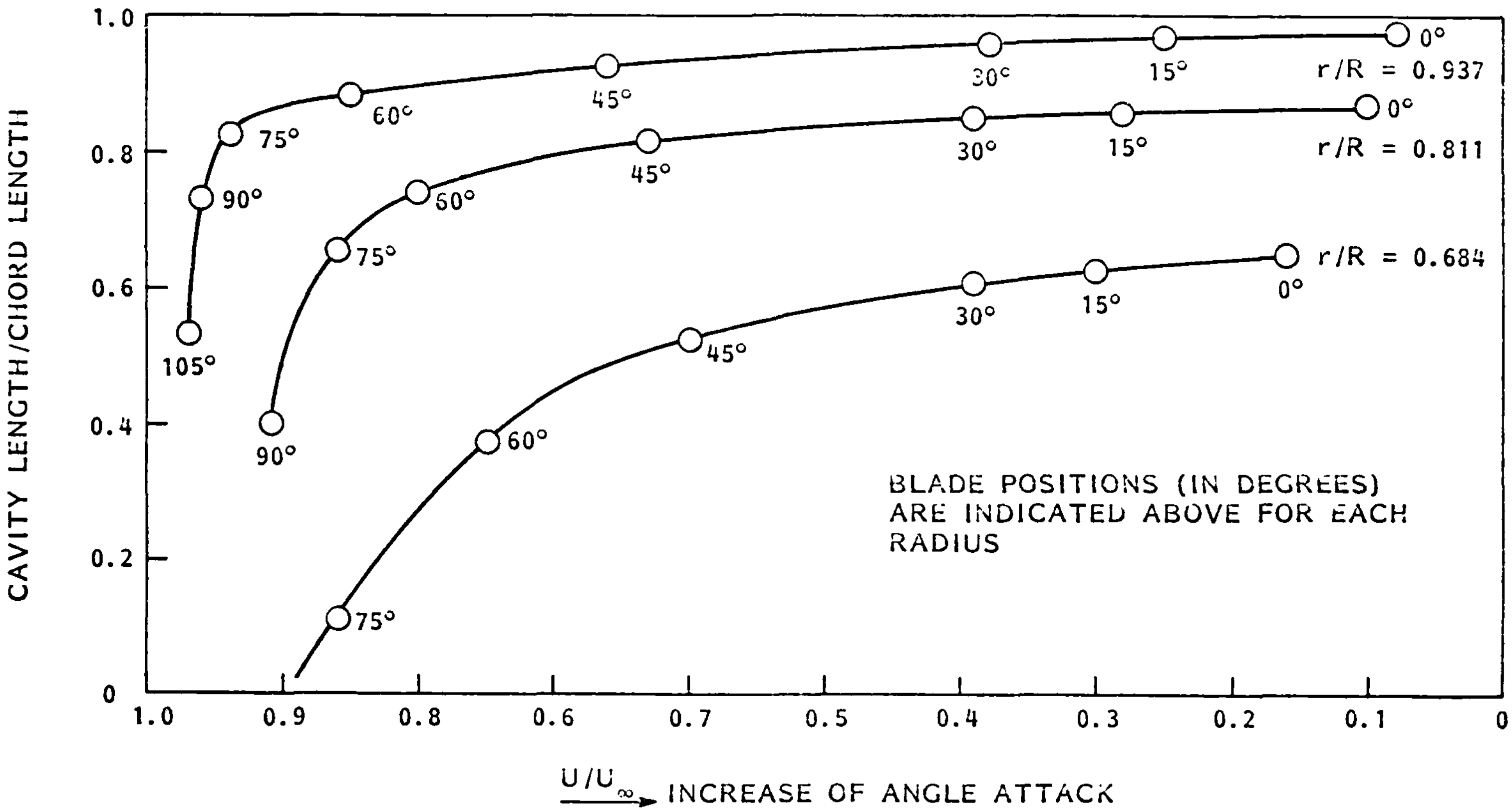


FIGURE 15 - VARIATION OF PREDICTED CAVITY LENGTH WITH AXIAL VELOCITY (PROPELLER IN SHIP WAKE)

END

DATE
FILMED

9 — 83

DTIC