

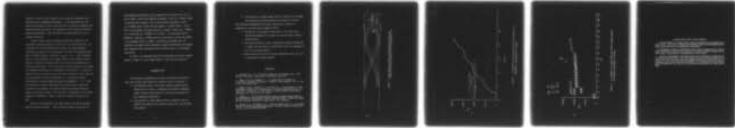
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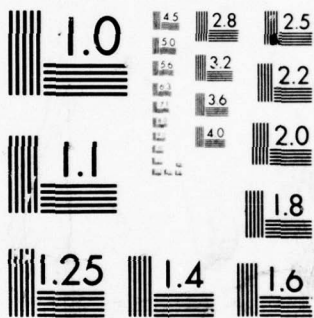
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6 ANALYSIS OF SES MODEL WAVEMAKING RESISTANCE  
USING LONGITUDINAL-CUT WAVE HEIGHT DATA

by

10 Bernard J. Young

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DEPARTMENTAL REPORT

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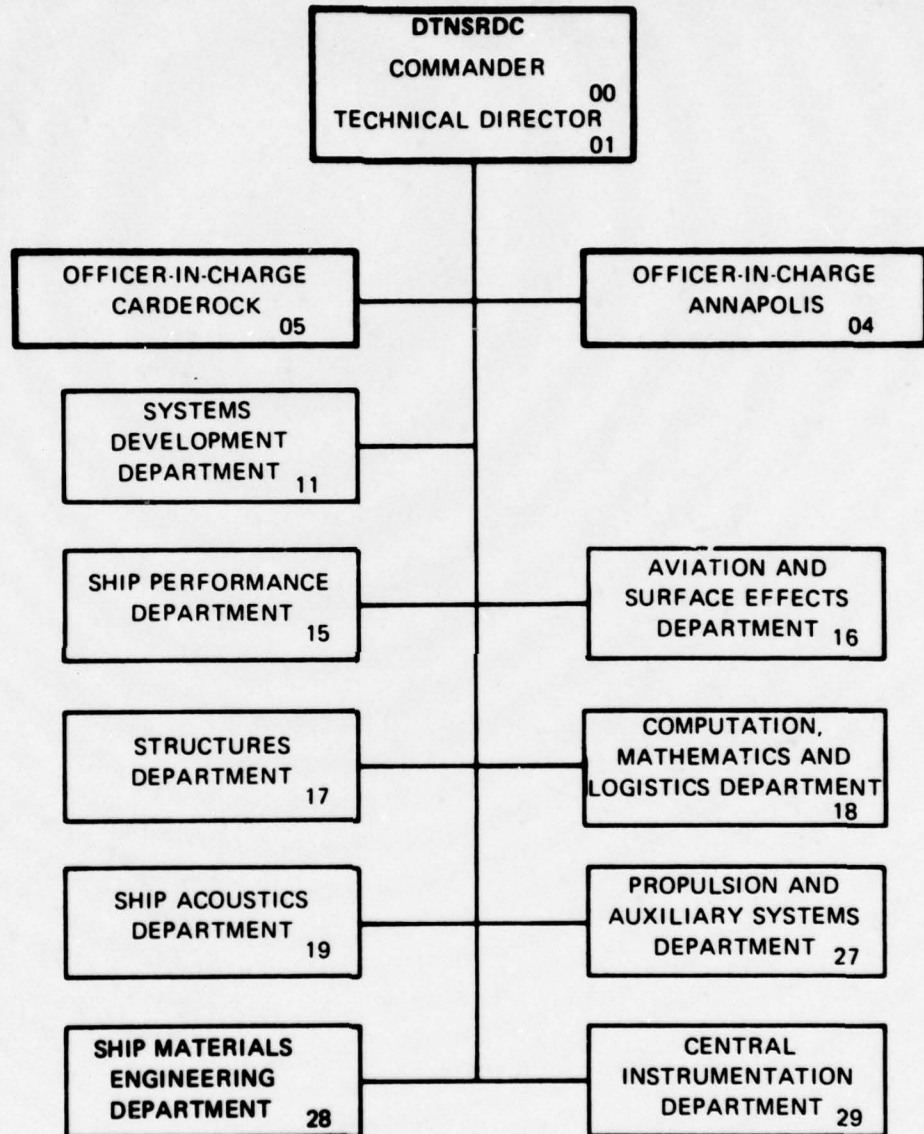
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1. REPORT NUMBER SPD-799-01 ✓	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ANALYSIS OF SES MODEL WAVEMAKING RESISTANCE USING LONGITUDINAL-CUT WAVE HEIGHT DATA	5. TYPE OF REPORT & PERIOD COVERED	
	6. PERFORMING ORG. REPORT NUMBER	
7. AUTHOR(s) Bernard J. Young	8. CONTRACT OR GRANT NUMBER(s)	
9. PERFORMING ORGANIZATION NAME AND ADDRESS David W. Taylor Naval R&D Center ✓ Bethesda, MD 20084	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Element 62543N Task Area SF 43421001 Work Unit 1-1500-100	
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Material Command Washington, D.C. 20360	12. REPORT DATE March 1978	
	13. NUMBER OF PAGES 12	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED	
	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)  Surface Effect Ship, Wavemaking Resistance, Wave Height		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) ✓ Calm water resistance tests on an L/B = 3.78 SES model were conducted in the Langley Field Towing Basin. During these tests model generated wave height data were taken along a line parallel to the model path. Results of this data at one speed are analyzed by the truncation correction method and the finite integral method to determine wavemaking resistance. The results are compared with resistance measurements and with the wavemaking predicted by a theoretical method. ↗		

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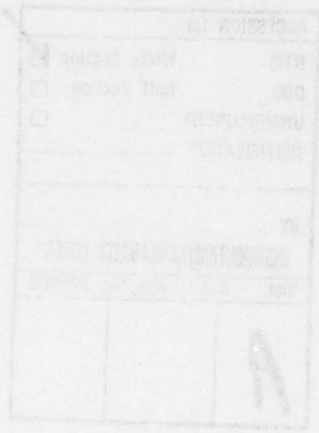
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NOTATION

<u>Symbol</u>	<u>Meaning</u>	<u>Dimensions</u>
B	Beam of Model or Cushion	L
$C_w$	Wave Resistance / $(\frac{\rho}{2} \ell^2 V^2)$	-
L	Length of Model or Cushion	L
$L_w$	Length of Fundamental Wave	L
$L_{cut}$	Length of Wave Cut	L
M	Truncation Point in Series for $C_w$	-
V	Speed of Model	$LT^{-1}$
b	Width of Tank	L
g	Acceleration in Gravitational Field	$LT^{-2}$
$\ell$	L/2	L
m	Integer Index	-
y	Distance from Model at Which Wavecut is Measured	L
$\alpha$	Parameter Describing Rate of Change at Bow and Stern of Pressure Distribution	-
$\beta$	Parameter Describing Rate of Change at Sides of Pressure Distribution	-
$\rho$	Mass Density of Water	$ML^{-3}$
$\theta_{Kelvin}$	Kelvin Wave Angle, Approximately 0.3398 Radians	-

## ABSTRACT

Calm water resistance tests on an  $L/B = 3.78$  SES model were conducted in the Langley Field Towing Basin. During these tests model generated wave height data were taken along a line parallel to the model path. Results of this data at one speed are analyzed by the truncation correction method and the finite integral method to determine wavemaking resistance. The results are compared with resistance measurements and with the wavemaking predicted by a theoretical method.

## ADMINISTRATIVE INFORMATION

This project was authorized by the Naval Material Command, Code 08T, Task Area SF 43421001, Program Element 62543N, and performed under David W. Taylor Naval Ship Research and Development Center Work Unit 1-1500-100.

## INTRODUCTION

During calm water resistance experiments in the Langley Field tank on an  $L/B = 3.78$  SES model having thin sidewalls<sup>1\*</sup> several longitudinal wave profiles were recorded to be used later in determining wave resistance. A sonic wave probe located at  $\frac{y}{b} = \frac{1}{3}$  was used to record wave height (at a rate of 50 samples per second) beginning before the passage of the model and continuing for some time after reflections were discernible. The position was chosen to be compatible with the finite integral longitudinal cut method of Moran and Landweber,<sup>2</sup> a method which does not require a wide tank. The position of the model with respect to the wave was not recorded.

---

\* References listed on page 9

The present project attempts to analyze the longitudinal cut data to determine wave resistance using two methods: 1) the truncation correction method described by Sharma, Eggers, and Ward,<sup>3</sup> and 2) the finite integral method of Moran and Landweber. The truncation correction method requires a wide tank ( $b/L > 3$ ) and a lengthy wave record ( $L_{\text{cut}}g/2\pi V^2 > 3$ ) before reflections. The finite integral method, specifically developed for finite width tanks makes use of waves reflected by the tank walls. It will be shown below that the truncation correction method is not suited to the data available because the data were taken too close to the wall. The portion of the wave record without reflections is too short for proper analysis. It will also be shown that, due to anomalies in the method, the wave record is too short for proper analysis using the finite integral method. However, some experience has been gained which deserves documentation and some results of limited accuracy are presented.

#### THE WAVE PATTERN

The following description of the free wave pattern produced by a moving pressure distribution, though simplistic, serves the purpose of illustrating the requirements of longitudinal cut methods. Free surface wave theory shows that transverse and divergent waves emanate from a spatial change in a moving pressure distribution. In the case of a surface effect ship or air cushion vehicle such changes take place at the perimeter of the pressure distribution and, perhaps, beneath the fan

outlets which feed air to the cushion. The latter will have no bearing on this discussion. In deep water the diverging waves form a pattern which radiates from the ship at the Kelvin wave angle:

$$\theta_{\text{Kelvin}} = \sin^{-1} \frac{1}{3} \quad (1)$$

In a towing tank these waves are reflected at the tank wall at the same angle.

The pressure distribution moving at speed  $V$  produces a wave of fundamental length

$$L_w = \frac{2 \pi V^2}{g} \quad (2)$$

and a spectrum of waves of shorter length. For the purpose of deriving the wave resistance from a single longitudinal cut, it is necessary to have a wave profile which contains at least one fundamental wave emanating from each point on the pressure distribution. In the case of thin ships, the minimum length of cut would be given by

$$\begin{aligned} L_{\text{cut}} &= L + L_w \\ &= L + \frac{2 \pi V^2}{g} \quad (\text{For a thin ship}) \end{aligned} \quad (3)$$

For the SES the required length is even greater as shown by Figure 1. In this case waves emanating from diagonal corners of the pressure distribution intersect longitudinal lines at points which are further apart than the length of the distribution. The extra distance is seen to be the width of the pressure distribution divided by the tangent of the

Kelvin angle. All of the information in the free wave system behind a moving pressure distribution should be contained in a record of length

$$L_{\text{cut}} = L + \frac{2 \pi V^2}{g} + \frac{B}{\tan \theta_{\text{Kelvin}}} \quad \text{(For a pressure distribution or a blunt ship)} \quad (4)$$

#### TRUNCATION CORRECTION METHOD

Besides the minimum length for the wave-cut record, the different longitudinal cut methods pose additional requirements. The truncation correction method requires that no reflections from the tank wall appear in the portion of the cut used for analysis. Data to be analyzed by this method should be taken close to the model ( $y$  slightly greater than  $\frac{B}{2}$ ). A very wide tank is desirable so that  $y \ll \frac{b}{2}$ . The conditions given by Equations (3) or (4) are sufficient to obtain a satisfactory estimate of the wave resistance, but the truncation correction to this estimate is based on the characteristics of the last wave in the record. Therefore a complete analysis requires waves beyond those found in a cut of length given by Equations (3) or (4).

The truncation correction method requires that the position of the model with respect to the wave record be known if the details of the wave spectrum are to be computed. If the position of the wave record is not known, the wave resistance may be determined but spectral information is meaningless.

Two other aspects of the truncation correction method should be mentioned. Recent experience by Ogiwara<sup>4</sup> indicates that satisfactory results can be obtained by this method if wave profiles are taken at the tank wall and divided by two. The second point to be made is that no wavecut method known to the author specifically treats the tank blockage effects on wave resistance.

#### FINITE INTEGRAL METHOD

A different set of requirements in addition to Equations (3) or (4) are placed on longitudinal cut records to be analyzed by the finite integral method. Derived specifically for use in small tanks, this method makes use of waves reflected from the tank walls. To do so the cut must be made at a value of  $y$  such that

$$\frac{4my}{b} \neq \text{Odd Integer for } m = 0, 1, 2, \dots$$

The analysis of a computed wave profile for a linearly varying source distribution (the distribution for an infinitely deep strut) indicates several anomalies occur as one varies the length of the wave profile and the number of terms in the series for the wave resistance coefficient. It is shown in Reference 2 that if the length of the wavecut is below a critical value, the series for  $C_w$  diverges. The length of cut for which this divergence takes place is dependent on the number of terms  $M$  in the series. In general the series will converge to the correct value

of  $C_w$  if the record is sufficiently long and  $M$  is sufficiently large. During the research reported here the author determined that for a fixed length of record, the result will also diverge if  $M$  is too large. This is presumed to be caused by numerical instability in the solution of a system of simultaneous linear equations of order  $2(M + 1)$  when inaccuracies occur in the right hand side; this behavior was not reported in Reference 2. Sufficient study of these anomalies has not been made either by the authors of Reference 2 or the author of this report.

Care should be given to avoid the case where the wave record is so long that waves from the side of the model opposite the probe are reflected, pass through the wake, and appear in the record. In passing through the rotational wake the waves will be distorted. It is not appropriate to analyze this type of record with the finite integral method which is based on potential flow theory.

Like the truncation correction method, the finite integral method does not require that the position of the model with respect to the wave profile be known if only the wave resistance is to be computed.

## RESULTS

One wave record was selected for analysis by the truncation correction method and the finite integral method. The selected record was taken at a speed near hump ( $V/\sqrt{gL} = 0.666$ ) with the model in the 63.5 kg condition and with seals set 2.54 cm above the keel. The basis for the

selection of this run was a desire to have large wave resistance and a relatively short fundamental wavelength. It was recognized that the wavecuts were made too close to the tank wall to obtain the complete wave pattern without reflections. The analysis by the truncation correction method was performed to show the effect such reflections have on the computed resistance.

Figure 2 shows the wave resistance coefficient obtained by the truncation correction method as a function of the truncation point. No correction for the truncation error was made. The wave resistance coefficient  $C_W$  appears to be approaching a constant value asymptotically when it suddenly begins to increase at  $L_{cut}/L = 7.20$ . Other increases seem to occur periodically as a longer portion of the available data is analyzed. Between each discontinuity in the slope the increases are of similar size and shape. This is the result one would expect as the energy from repeated reflections is reintroduced in the analysis. It should be pointed out that the value of  $C_W$  at the first discontinuity falls short of the  $C_W$  predicted by Doctors and Sharma<sup>5</sup> for a rectangular pressure distribution of the same length and beam with parameters  $\alpha = 5$ ,  $\beta = 100$ . That prediction, based on linearized free surface theory, allows wave resistance to be computed for pressure distributions having different slopes at the ends and sides. This shortfall is comparable to the results presented in Reference 3, Figure 5, when no truncation correction was made.

Results of the analysis of the same record by the finite integral method are given in Figure 3. Here the partial sums of the series for

wave resistance coefficient  $C_W$  are presented for analyses to 30, 21, 15, and 12 terms. The 30 term analysis approaches a value  $C_W = 0.001775$  after 9 terms and then diverges. The 21 term analysis approaches a value  $C_W = 0.001819$  after 9 terms and then begins to increase slowly. The 12 and 15 term analyses are almost identical through 12 terms ( $C_W = 0.001853$  for 12 terms and  $C_W = 0.001886$  for 15 terms). The resistance test of Reference 1 gives  $C_W = 0.00189$  and the  $C_W$  predicted by Doctors and Sharma in an unbounded fluid is 0.00202. The Doctors and Sharma result is expected to be higher since rectangular pressure distributions have higher wave resistance than distributions with rounded corners, L/B and weight being equal.

In view of the anomalies described in discussing the finite integral method, a longer cut and a higher number of terms would be desirable.

#### RECOMMENDATIONS

The following recommendations are made concerning the analysis of other wave records taken during the resistance tests of Reference 1:

- 1) The analytical basis of the finite integral method requires further study in order to understand the anomalies regarding length of record and truncation of the series expression for wave resistance coefficient.
- 2) Other wavecuts at lower speeds should be analyzed to see if measured and computed wave resistance agrees with that obtained from wavecuts.

- 3) Other wavecuts at higher speeds should be analyzed to determine the significance of wave resistance attributable to skirts.

The following recommendations are made concerning the conduct of longitudinal cuts which may be taken in future:

- 1) The position of the model at some point of the wave record should simultaneously be recorded on a second channel using an optointerrupter.
- 2) Wave records should be taken a considerable distance downstream to insure that the record is sufficiently long to be analyzed by any of the suitable methods.
- 3) Wavecut analysis should be performed immediately after each run by the onboard carriage computer.

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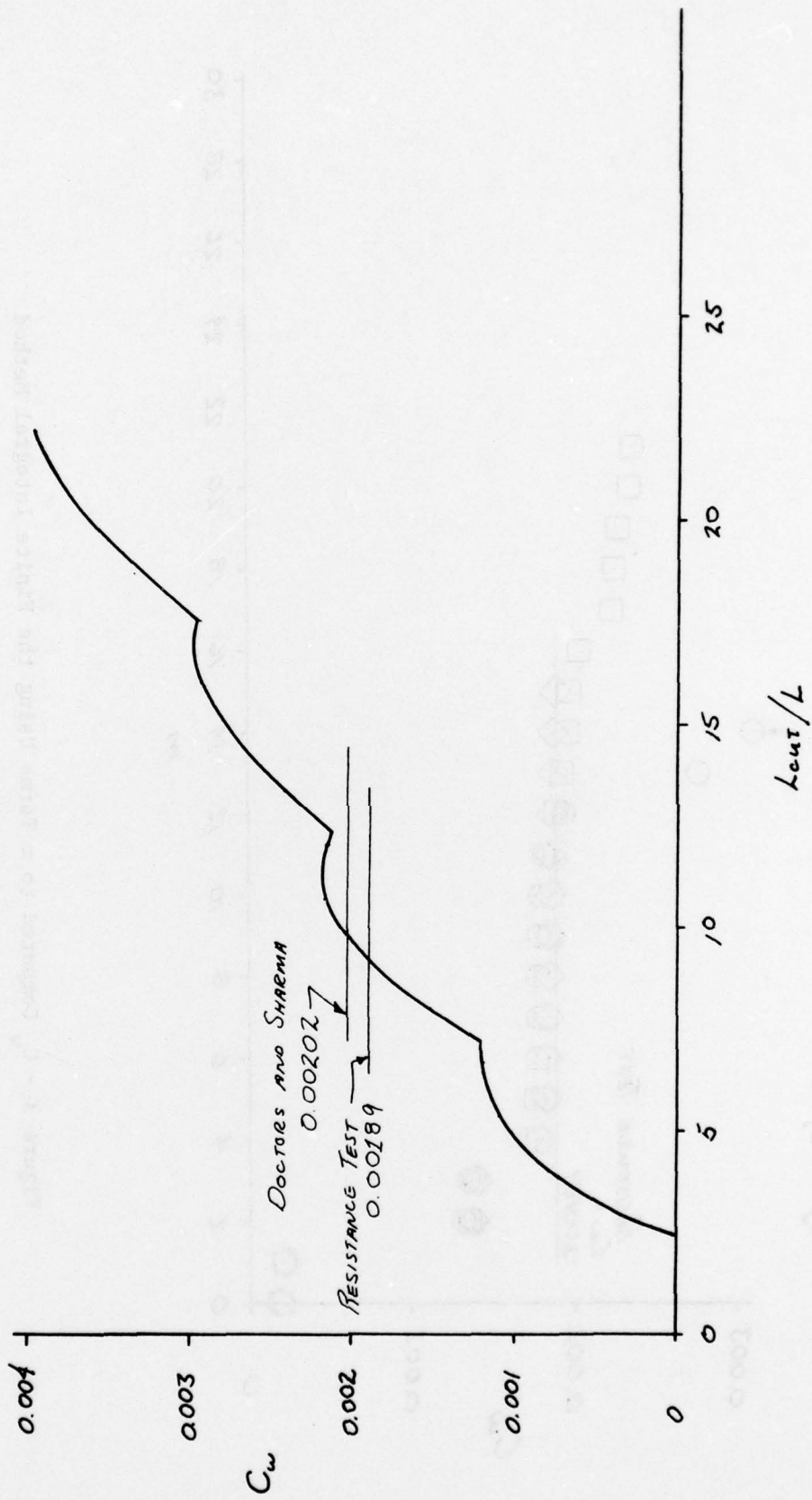


Figure 2 -  $C_w$  Computed by the Truncation Correction Method as a Function of Longitudinal Cut Length

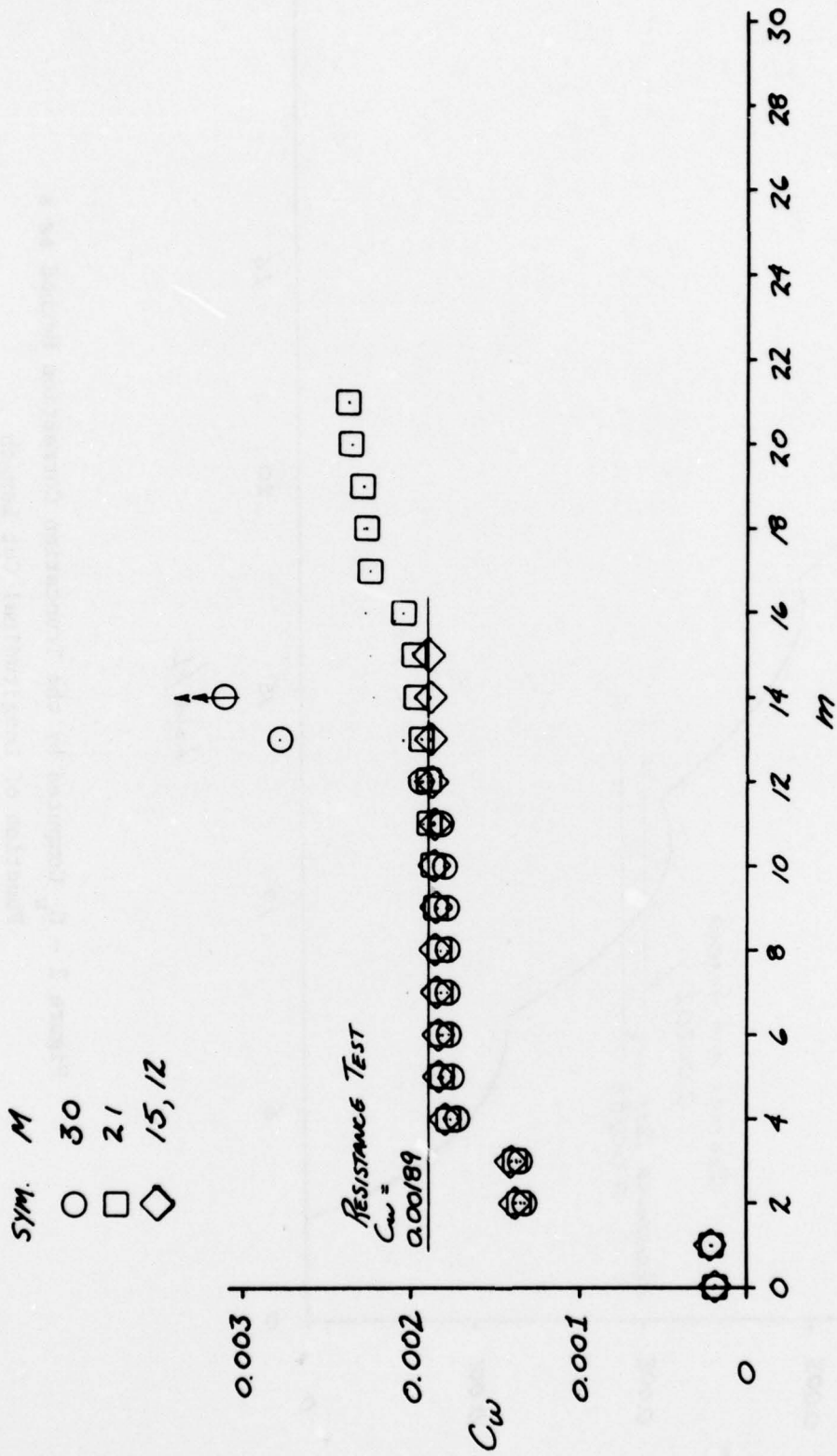


Figure 3 -  $C_w$  Computed to  $m$  Terms Using the Finite Integral Method for Analyses Performed to  $M$  Terms

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